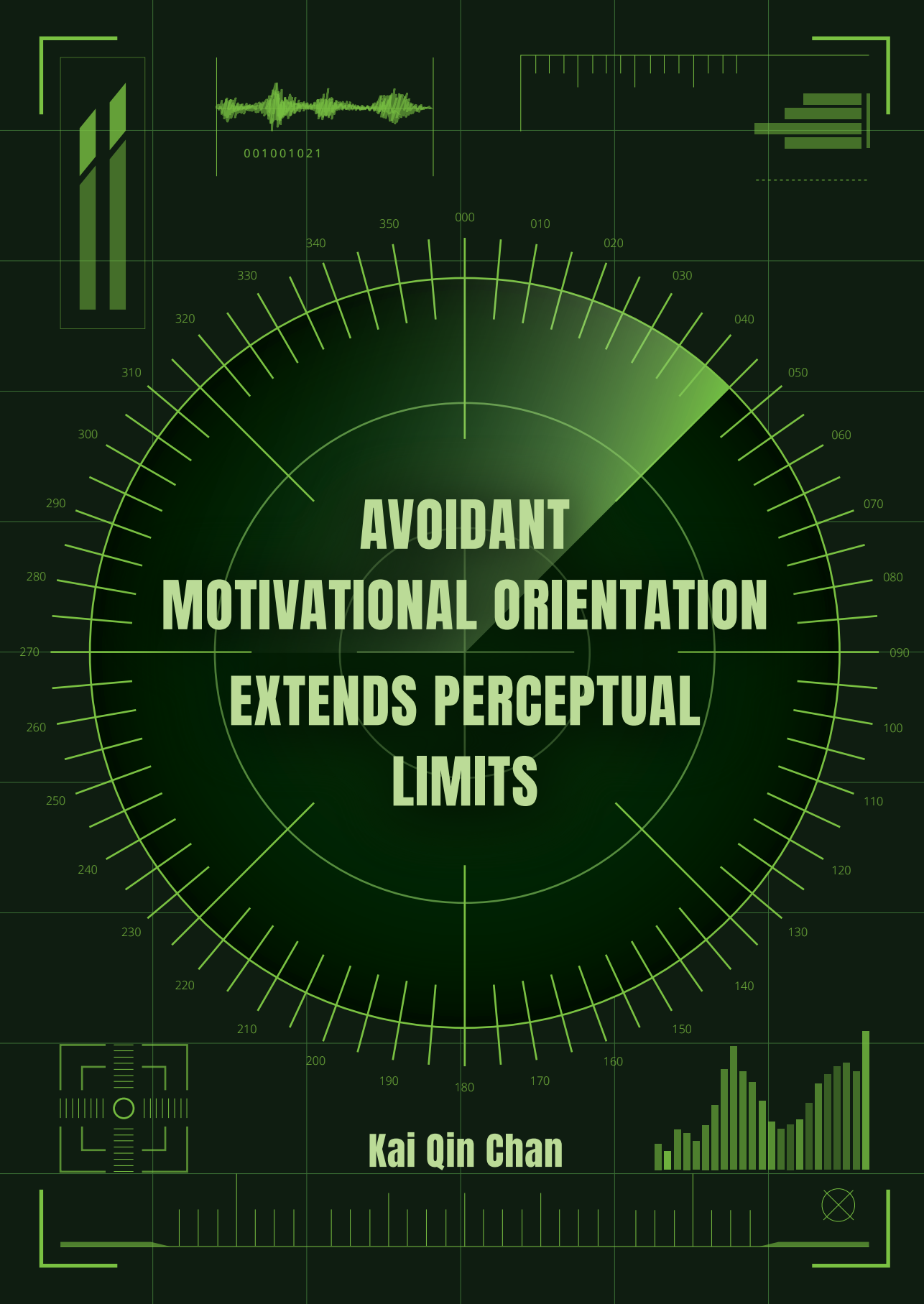

AVOIDANT MOTIVATIONAL ORIENTATION EXTENDS PERCEPTUAL LIMITS

Kai Qin Chan

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Contents

“Now you see it, now you don’t.”

PREFACE

Hold this page one arm's length from you and then take a look at Figure (i). How many circles can you see? Most people will have no problems seeing the first six, but they might miss the seventh, eighth, and ninth.

Figure (i). Circles in decreasing contrast from 1 (darkest) to 9 (faintest).

Human sensory systems are well-adapted to detect things within our ecological niche. Being able to detect contrast differences from the first seven circles is usually sufficient for our daily life. But sometimes objects are not always as obvious as we would like them to be. On foggy or rainy days, the precipitous curb just outside Basisschool de Akker at the junction between Akkerlaan and Veldstraat can be quite difficult to see when I am cycling from my house to Radboud University. (In fact, I once misjudged where the curb was and crashed into it during a rainy evening.) Even the best detection mechanisms—human or nonhuman—will have their own limitations, especially when the intensity of the target is extremely low. Nevertheless, it is important to be able to detect them because they inform us about the state of our immediate environment.

Psychologists studying perceptual abilities (psychophysicists) have mainly been concerned with understanding how the structural

characteristics of a stimulus influence the perceptual detection (Fechner, 1860/1966; Goldstein, 2001; Stevens, 1961, 2002). For a long time, except for a brief period in the 1950s during the so-called *New Look* paradigm (Bruner, 1957; Erdelyi, 1963), detection thresholds were thought to be immutable from an individual's motivational or emotional states; any evidence that suggested otherwise was perceived to have a psychoanalytic sting to it (Bruner, 1992, 2010). Therefore, in prominent handbooks in experimental psychology or specialist medical textbooks, there has been no mention whether motivation or emotional states affect detection thresholds.

Recently, this view has been challenged by researchers who have found that emotions improve contrast sensitivity, spatial resolution, and temporal resolution (Bocanegra & Zeelenberg, 2009, 2011a, 2011b; Bruner, 1957; Phelps, Ling, & Carrasco, 2006; Sherman et al., 2012). However, these studies focused only on vision; whether these effects extend to other sensory modalities is yet unknown. A science about "(e)motivational psychophysics" would be incomplete if based solely on vision.

In this dissertation, broadly speaking, I study how motivational orientation lowers sensory thresholds. In reality, my line of work began by studying the effect of avoidant emotions on sensory thresholds, but as it progressed, it became clear that motivational orientation was a crucial factor inherent in the emotions that were studied. Theorists have claimed that humans have two broad motivational orientations, approach and avoidance, and these can manifest as specific emotional states (Elliot, 2008). Research has shown that general avoidance motivational orientation and specific avoidant emotions are functional because they enhance vigilance. My research focuses on one type of

vigilance, detection thresholds of faint stimuli — stimuli that are at the boundaries of conscious experience. I argue that under an avoidance motivational orientation or when experiencing an avoidant emotion, it is functional to have a lowered threshold because this would allow perceivers to detect extremely faint stimuli. In other words, general avoidant orientation, as well as specific avoidant emotions, allow a very weak stimulus (comparable to #8 or #9 in Figure i) which normally appears undetectable to be detected.

In Chapter 1, I present a framework on the influence of emotional states on *perceptual limits*, boundaries placed on perception abilities. Perceptual threshold—the main focus of my research—is one of these limits. I explain the functions of emotions; define what constitute perceptual limits or not; review what has been found in the literature; and suggest possible mechanisms at various levels – from neural to physiological to evolutionary processes.

In this preface I started with examples from vision to illustrate examples of detection thresholds. My work, however, focuses on olfaction and audition. In Chapter 2, I present empirical studies testing the influence of avoidant emotions on olfactory detection thresholds. Thus, in this line of research, I tested that avoidant emotions, disgust and fear, lower sensory thresholds.

In Chapter 3, I investigate whether disgust lowers olfactory thresholds because disgust influences general olfactory sensitivity (the "general sensitivity hypothesis"), or because of the fit between the negative valence of the scent and disgust (the *valence-fit hypothesis*). I tested this valence-fit hypothesis stringently using scents of opposite valences.

In Chapter 4, I investigated the influence of motivational orientation on perceptual limits in a different modality. I tested how and why general approach and avoidance motivational orientations influence auditory thresholds.

Each chapter of this dissertation is based on a scientific article. Therefore, each chapter can be read independently, and in any order. Some overlap in terms of theoretical background and methodology may be encountered. I report all studies conducted within these lines of research. Data and syntax are available upon request.

CHAPTER 1

Do Avoidant Emotions Extend Perceptual Limits?*

Abstract

The functions of the avoidant emotions fear and disgust in guiding behaviors, cognition (e.g., attention, memory, etc.), and perceptual processes (e.g., intensity estimates) have been well-established. Here we focus on a specific aspect of perception that has gained interest in recent years, namely, perceptual limits — *the extraordinary achievement of a perceptual outcome*. We review relevant research on vision, olfaction, somatosensation, and audition, showing that avoidant emotions are often capable of extending our sensory capabilities. Precise mechanisms of these effects deserve greater integrative research efforts in the future. We also highlight that simple theorizing based merely on the functional aspects of emotion and perception may not be fruitful. Instead, investigators should consider how evolutionary, physiological, and neural mechanisms converge in shaping sensory capabilities.

* This chapter is based on: Chan, K. Q., Clore, G. L., Holland, R. W., & van Knippenberg, A. (in-prep). *Do avoidant emotions extend perceptual limits?*

Don't we sometimes wish that we could see better, for example, when searching for our house keys in complete darkness or driving through fog? Humans have poorer vision compared to many animals, in part because the human eye lacks a large eyeball, a large lens, a large optical aperture, and a tapetum lucidum (retinal refractor). These are unchangeable morphological and anatomical constraints. However, even when bounded by these constraints, recent research has revealed that we can nevertheless have better visual capabilities under certain motivational and emotional states (e.g., Langer, Djikic, Pirson, Madenci, & Donohue, 2010). The purpose of this article is to review research on how motivational and emotional states influence *perceptual limits*, boundaries placed on perception abilities, such as the faintest light, smell, or touch that one can detect.

This chapter focuses on the perceptual limits that have been found in various sensory modalities, and how emotional or motivational conditions affect them. We adopt a functional view of sensory mechanisms based on what a given sensory system can or cannot do, and examine how those functions are affected as part of emotional or motivational states. Our ultimate aim is to review relevant research and to chart new territories for future research. This chapter is divided into six sections. In the first section, we outline the functionalities of avoidant emotion. In the second section, we define *perceptual limits*, explain what constitutes perceptual limits or not, and list some examples. In the third section, we review relevant research how avoidant emotions change perceptual limits; this review contains findings mostly from vision because research within this area has almost exclusively focused on visual processing. In the fourth section, we introduce and discuss our own work in olfaction and audition. Then,

we speculate on the possible mechanisms that lead avoidant emotions to change perceptual limits, and finally contemplate some future directions.

The functions of avoidant emotions

Emotions are short-lived psychophysiological phenomena that provide information and motivation for adapting to changing environmental demands (Frijda, 1994; Levenson, 1999). Psychologically, emotional reactions can alter attention, regulate cognitive processing, and affect behavioral inclinations. Physiologically, emotional reactions may be apparent in facial expressions, muscle tone, voice prosody, as well as effect changes in the autonomic nervous system and endocrine activity. Emotions represent the position of individuals relative to their environment, which may include inclinations to approach or avoid certain people, objects, actions, and ideas (Levenson, 1999). It is assumed that such bodily and behavioral modes of representing emotionally significant events are functional, allowing perception, thought, and action to be tuned to the situation one is in.

Emotion researchers have studied many emotions, such as happiness, sadness, fear, anger, disgust, surprise, contempt, guilt, embarrassment, shame, amusement, sympathy, love, jealousy, pride, schadenfreude, and so on. The variety of emotions have also led some researchers to devise taxonomies, classifying emotions into categories such as basic–secondary (Ekman, 1992), positive–negative (Watson & Tellegen, 1985), self-conscious–non-self-conscious (Tracy, Robins, Tangney, 2007), approach–avoidance (Elliot, Eder, & Harmon-Jones,

2013). Here we focus on one particular class of emotions: avoidant emotions.

Avoidant emotions operate in part to prepare the body for dealing with particular kinds of threats and challenges. Avoidant emotions, such as fear and disgust, seem to serve this function. When fear is aroused, cardiovascular activity is often raised to levels beyond those thought to be healthy for long-term survival, but these increases may be useful – and perhaps necessary – for the short-term coping with the immediate threat, such as escaping (Levenson, 1999). Similarly, disgust may involve constriction of air passages, increases in the sensitivity of the gag reflex, and other reactions that would not be optimal for the goal of taking in food and oxygen, but which might serve the short-term goal of rejecting noxious and harmful substances (Schaller & Duncan, 2007).

Avoidant emotions are negative in valence. However, not all negative emotions are avoidant. Sadness and anger are both negative emotions, but sadness is not avoidant and anger is typically considered to be an approach emotion (e.g., Carver & Harmon-Jones, 2009). What distinguishes avoidant emotions from other negative emotions is that avoidant emotions involve the underlying core motivation to protect the self from harm (Neuberg, Kenrick, & Schaller, 2011). Neuberg and colleagues (2011) proposed that humans have a threat management system, a precautionary system consisting of a suite of components that maximizes evolutionary fitness. The avoidant emotions, fear and disgust, play a crucial role in this threat management system because they motivate and coordinate adaptive behaviors.

At times, however, threats are not easily discernable. Much like trying to find a tiny cluster of yellowish-grey mold on soon-to-be-

expired brown bread, the ability to detect, discriminate, and subsequently identify these threats places great demands on an individual's cognitive and perceptual systems. Levenson (1999) theorized that emotions lead to several "response packages" (p. 485), and enhancing an individual's perceptual capabilities is one of them. Next we focus on a particular type of enhanced perceptual capability: the extension of perceptual limits.

Perceptual limits

Desirable objects and situations—such as nourishing food, protective shelter, and suitable mates—must be sought out and approached. Dangerous objects and situations—such as precipitous drops, falling objects, and hungry predators—must be avoided or fled from. Thus, to behave in an evolutionarily adaptive manner, individuals must somehow obtain information about what objects are present in the world around them, where they are located, and what opportunities they afford us. All of the senses—seeing, hearing, touching, tasting, and smelling—participate in this endeavor (see Palmer, 1999).

The existing literature includes claims that avoidance emotions enhance "perception" (for a review, see Brosch, Scherer, Grandjean, & Sander, 2013; Phelps, 2006; Stefanucci, Gagnon, & Lessard, 2011; Zadra & Clore, 2011). In some research, avoidance is implicated in the stimuli themselves. For example, visual search for threatening faces is faster (e.g., Hansen & Hansen, 1988); negative information "pops" into consciousness more frequently in binocular rivalry tasks (e.g., Yang, Zald, & Blake, 2007). In other research, avoidant emotions constitute psychological states experienced by the observer. For example, fear makes objects look bigger (e.g., Leibovich, Cohen, Henik, 2016; Vasey,

Vilensky, Heath, Harbaugh, Buffington, & Fazio, 2012; but see Firestone & Scholl, 2014, in-press), hills steeper (e.g., Proffitt, 2009; Stefanucci, Proffitt, Clore, & Parekh, 2008), sounds louder (Siegal & Stefanucci, 2007), and selected neural regions are activated more strongly (Vuileumier, 2009).

However, such enhancement in perception does not per se imply any change in perceptual limits because not all perceptual tasks involve perceptual limits. Consider the finding that approach motivation involves a right-side bias (Roskes, Slighte, Shalvi, & De Dreu, 2011, 2014), which can be measured using a line-bisection task where individuals have to indicate the mid-point of a horizontal line. This is a visual perception task, but it does not share the qualitative nature of a task involving perceptual limits, such as an auditory threshold task where individuals report the softest sound that they can hear. In addition, inherent in the connotation of *limits* is that the underlying unit of measurement must be on some continuous measure. Thus, the ability to discriminate the scent of roses from that of lilies is not a perceptual limit, but the minimum concentration required for an individual to detect a rose scent is.

People tend to think of limits as fixed. The idea that perceptual limits may be extended might sound paradoxical, because a limit that can be extended was never a limit in the first place. In reality, limits are always bounded by two things. First, perceptual limits are in part determined by the anatomy of our sense organs. For example, the position of our eye sockets determines binocular vision, trading better visual acuity for a narrower field of vision; or the position of our pinnae (the "outer ear"), predisposing us to localize sounds better when they are in front of us than when they are behind us (Middlebrooks & Green,

1991). No matter how hard we try, our field of vision cannot exceed 120 degrees, and localization of sounds frontward is always better. These are typical types of perceptual limits imposed by our physiology. If we develop larger pinnae, localizing sound may improve (Hofman, Riswick, & Opstal, 1998); if we develop retinal refractors, we may acquire night vision like cats.

Second, perceptual limits are bounded by the circumstances of measurement. People used to think that the smallest distance between two points that our eyes can tell apart is 0.1 mm, until magnifying glasses (and subsequently, the optical microscope) was invented (Hooke, 1665). Similarly, auditory thresholds would certainly be lower when an observer is in a quiet room rather than a noisy one, or one can surely see farther with binoculars than without. Therefore, *perceptual limits* can be defined as *the extraordinary achievement of a perceptual outcome*[1] within a given situation (e.g., under optimal laboratory conditions, unaided by artificial equipment, etc.). In other words, the pertinent question is: how much better can individuals in [state X] do [perceptual activity Y]? Using this definition, judgments of an object's size (e.g., Leibovich et al, in-press; Vasey et al, 2012), angle (e.g., Proffitt, 2009; Stefanucci et al., 2008), or intensity (Siegal & Stefanucci, 2007) do not constitute limits because they do not probe for "extraordinary" outcomes; measures of neural responses (e.g., Kass, Rosenthal, Pottackal, & McGann, 2013) or psychophysiological events (e.g., event-related potentials, pupil dilation, etc.) would not qualify, because they

[1]This is not the same as "the achievement of an extraordinary perceptual outcome" (e.g., visual illusions or hallucinations). The position of the adjectival modifier "extraordinary" is important.

lack the qualia to be considered a "perceptual outcome".[2] It is important to make the distinction between whether the perception occurs as an independent variable or as a dependent variable. Our focus (avoidant emotions affecting perceptual limits) entails that the dependent variable must be a perceptual outcome, and avoidant emotions must be experienced by the observer. Although functional MRI scans or psychophysiological measures can be obtained while participants are exposed to fear- or disgust-inducing pictures and these dependent measures may be *affected by* seeing these pictures, these dependent variables are not "perceptual" in any meaningful way.

Within these physiological constraints and circumstances of measurement, here we propose that without the need to alter our anatomy or strapping on artificial equipment, avoidant emotions experienced by the observer can extend perceptual limits. Table 1 lists some examples of perceptual limits, and these are explained briefly in the Appendix. However, only some have received support of avoidant emotions altering these limits.

[2] This is also known as the "hard" problem of consciousness (Chalmers, 1995) – even if we could map all neural correlates of consciousness, we still cannot understand the subjective experience of the person.

Table 1.

Examples of perceptual limits within each sensory modality.

Modality	**Possible perceptual limits**	**Examples**
Vision		
	Contrast sensitivity	Faintest difference in shades
	Detection threshold	Faintest light; stereoscopic
	Spatial resolution	depth
	Temporal	Smallest gap
	resolution	Fastest flicker
	Spectral sensitivity	Infrared or ultraviolet
Audition		
	Detection threshold	Softest sound
	Temporal	Hearing tones as separate
	resolution	Lowest (< 20 Hz) or highest
	Frequency	(> 20 kHz) tones
	Localization	Minimum auditory angle
Olfaction		
	Detection threshold	Faintest smell
	Localization	Smallest olfactory angle
Somatosensation		
	Detection threshold	Softest touch
	Spatial resolution	Grating orientation
	Temporal	discrimination
	resolution	Vibrating pulses
Gustation		
	Detection threshold	Least concentrated tastant

The influence of avoidant emotion on perceptual limits in vision

Avoidant emotions activate a set of response packages that have been selected by evolutionary processes to maximize an organisms' fitness, and enhancing perceptual capabilities is one of them (Levenson, 1999). The fact that emotions influence "perception" is not new; the idea dates back to the *New Look* approach to perception (Bruner, 1957), which regards perception as a constructive process based on top-down factors, such as individuals' expectations, needs, and desires. Two classic examples are how poorer individuals overestimate the sizes of coins (Bruner & Goodman, 1947), and how individuals tend to interpret an ambiguous stimulus in a way that favors their desired outcomes (Balcetis & Dunning, 2006). However, overestimating coin sizes and wishful seeing are not perceptual limits per se.

The novel idea we advance here is that avoidant emotions influences perceptual limits, not merely "perception", which is sometimes used as a nondescript term. The benefit of having extended perceptual limits is clear: When perceptual limits are extended, we can accurately perceive things that we would normally not be able to perceive. In some ways, this is similar to how we can see minute details of things when our spatial resolution is artificially extended with magnifying glasses. Although we listed many types of perceptual limits in Table 1, only a few have been studied in relation to avoidant emotions. We first review these in the domain of vision where most research has been done. This review is meant to be exhaustive to the best of our knowledge. However, we anticipate that readers may occasionally, feel that we have omitted some evidence that *appears* to support our idea of perceptual limits but does not meet our criteria as

perceptual limits. We document such instances in Footnote 3.[3] In the following section, we then discuss work that we have done on testing perceptual limits in other modalities.

Temporal limits

Visual scenes rarely remain static. Until photography was invented, it was debatable whether a galloping horse lifts all its four hooves off the ground at any one time (cf. Holcombe, 2009) because there is a temporal limit on vision. A greater temporal limit could accelerate visual processing of cues related to type, motion, and direction. In a prototypical setup, an observer is asked to report two letter targets embedded in a stream of rapidly presented digits. When two visual images (targets) are flashed very quickly in close succession to each other, individuals are typically able to detect the first one without any awareness of the second image (Shapiro, Raymond, Arnell, 1997). This attentional blindness, also termed *attentional blink*, is a result of a visual buffer that is unable to cope with the demands of the

[3] Several studies appear to provide evidence that avoidant emotions enhance perceptual limits but we argue that they veer away from the cause-and-effect that we imply in this article. Consider two studies here: (1) participants were faster to search for fear-relevant targets (snakes or spiders) in grid-pattern arrays of fear-irrelevant distractors (e.g., flowers or mushrooms; Öhman, Flykt, & Esteves, 2001); (2) negative emotional stimuli pops into consciousness faster in binocular rivalry tasks than neutral stimuli (e.g., Alpers, Ruhleder, Walz, Mühlberger, & Pauli, 2005). Although time is a ratio-scale, continuous measure with a lower limit (i.e., 0 sec), one must note the emotion is integral in the stimuli and was not experienced exogenously (i.e., independently) from the stimuli. One may argue that endogenous experience of emotions triggered by the stimuli also demonstrates that avoidant emotions enhance perceptual limits. This argument, however persuasive, is logically problematic: Experiences triggered by the stimuli therefore leads the stimuli to be more easily detected begs the question "How does one know an object exists in the first place?"

situation. However, fearful stimuli seem to be the exception. When the second visual image has a fearful quality, the attention system gives it priority in processing (Anderson, 2005) such that individuals are now able to notice it.

The attentional blink requires a first task as a trigger. However, there are other temporal tasks that do not require this. A temporal resolution is the interval over which the system blurs information together. When two images are located in the same space but are displaced temporally, the result is a (con)fused image. For example, when the word "jump" and "pink" are alternated in the same location at 5 Hz (100 ms/word), observers sometimes report seeing "junk" or "pimp" (Holcombe & Judson, 2007). Both types of limits (i.e., attentional blink and temporal resolution) are probably caused by limits at high-level processing stages. As such, emotion effects applicable to the attentional blink may also be observed in temporal resolution tasks. In one experiment (Bocanegra & Zeelenberg, 2011a), a fearful or neutral cue was presented prior to a visual target. The visual target (e.g., a circle) was either presented twice, each separated by a brief 10 – 30 ms temporal gap, or continuously for the same amount of time. Participants were asked to detect whether they saw a "flicker" or not. If fear improved temporal resolution, participants would tend to notice the brief temporal gap as a flicker, and indeed they were more accurate in identifying these flickering trials. Taken together, the attenuation of attentional blindness for fearful stimuli (Anderson, 2005) and the improved flicker detection due to fearful cues (Bocanegra & Zeelenberg, 2011a) both show that temporal limits are improved under fearful conditions.

Spatial limits

Often it is not only useful to know whether an object is present or not, but also to identify what that object is. While high contrast sensitivity improves the ability to distinguish foreground objects from their backgrounds, identifying the object requires more than just that; object identification would benefit much from having high spatial resolution as well. From a distance, a grey object on the ground can be a rock or a rabbit; falconiformes (eagles, falcons and hawks) can recognize small prey from large distances because survival in their natural habitat has required adaptation of its visual system to achieve high spatial resolution (visual acuity).

In humans, investigators have explored whether emotions benefit spatial resolution. Specifically, in one experiment (Bocanegra & Zeelenberg, 2011b), observers had to indicate whether a Landolt figure contained a small spatial gap or not (see Figure 1). The presentation of the square was preceded by a fearful or neutral face. The authors controlled for the effects of attention by presenting the face either at the same location as the Landolt figure, or at a different location. The results indicated that fearful faces presented at the same location improved spatial resolution over neutral faces. Making fine visual discriminations should be particularly adaptive for identifying things from a distance, and the presence of threat appears to enhance spatial resolution.

Figure 1. A Landolt circle with a gap at the top. Circles and gaps of varying sizes are commonly used in optometry and research to test visual acuity.

Contrast sensitivity

Contrast sensitivity, the ability to detect small increments in shades of gray on a uniform background, is one of the main limiting factors in a wide variety of visual tasks. In other words, contrast sensitivity defines the threshold between the visible and invisible (Pelli & Bex, 2013). It is important in some occupations, such as for a radiologist to detect a tumor on an x-ray, but it is also important in daily functioning, especially in situations of low light, fog, or glare, when the contrast between objects and their background is reduced. Driving at night or through fog is an example of an activity that requires good contrast sensitivity for safety. More generally, sensitivity to contrast provides us with information about the boundaries of objects and facilitates object identification.

Objects are more easily seen if the contrast between the focal target and the background is high. The visual system has evolved ways to deal with low contrast objects. One of the ways is to enhance the contrast sensitivity so that foreground-background shade differences are amplified. Contrast sensitivity was thought to be changeable only by organic factors, such as macular pathologies (see Pelli & Bax, 2013), or neurochemical factors (Bubl, Kern, Ebert, Bach, & van Elst, 2010). However, recent research has shown that emotions can modulate contrast sensitivity too. One of the ways emotions are functional is that they help us to detect relevant cues in the environment.

It is functional to improve contrast sensitivity in states of fear so that subtle threat cues can more easily be seen. Indeed, in the first demonstration of its kind, researchers found that fear involves improvement in visual contrast sensitivity (Phelps, Ling, & Carrasco, 2006). The experimenters presented fearful or neutral face cues prior

to four peripheral Gabor patches (see Figure 2), which were at near-threshold contrast. One target Gabor patch had a different tilt than the others and the observer's task was to indicate which of the four patches was the target. The researchers found that masked presentation of a fear face improves contrast sensitivity, even after controlling for the possible confound of attention. Similarly, individuals who underwent an aversive cold pressor task also showed greater contrast sensitivity (Woods, Philbeck, & Wirtz, 2013).

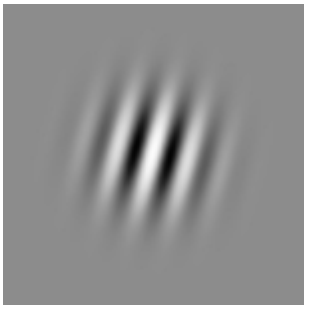


Figure 2. Gabor patches are sinusoidal gratings used in contrast sensitivity research. Various components of a Gabor patch can be specified, such as the grating frequency, size, contrast, orientation, and many more.

In another line of research, Sherman, Haidt, and Clore (2012) found that disgust enhanced the visual system's ability to detect differences in coloration. In one experiment, participants viewed either neutral, disgust-, or fear-inducing pictures and then engaged in a perceptual discrimination task. Faint-grey digits were presented against a light or dark background, and participants had to read the number. This method essentially assesses contrast sensitivity, although not with Gabor patches as in Phelps et al. (2006). The researchers found that in the disgust condition, perceptual discrimination was superior among

individuals high in disgust sensitivity. However, this was true only when targets were presented against a light background. The idea is that in most ecological settings, dirt or impurities appear on light-color backgrounds (e.g., stains on the toilet bowl), rather than against dark-color backdrops. Disgust is a powerful emotion that presumably serves this goal of avoiding infection, and as a result, leads to better detection of possible impurities. Consistent with the results of Phelps et al (2006), fear also increased contrast sensitivity against both light and dark backgrounds.

Stereoacuity

Depth perception is greatly improved by binocular vision because each of our two eyes, being slightly apart, receives slightly different visual information, which the brain then integrates to give information about depth. In a three-dimension world, having accurate depth perception – being able to judge spatial distances between the self and an object – could prove essential for avoiding objects or navigation. Depth perception can be measured by presenting participants with two rods of varying distance from the self, and having participants judge which of the two rods was closer in depth to their location. The minimum distance needed to perceive a distance in depth is the stereoscopic depth threshold. In one experiment (Woods et al., 2013), it was found that when participants experienced an aversive cold pressor task, participants showed lower depth threshold. That is, participants were better able to perceive minute differences in distance between themselves a target object.

Beyond vision: Effects of avoidance emotions in olfactory and auditory threshold

The research reviewed thus far on temporal resolution, spatial resolution, contrast sensitivity, and stereoacuity has exclusively focused on vision. If avoidant emotions are functional for perception, these functional benefits may extend to other modalities as well. Interestingly, with the exception of a brief report in somatosensation (Kelley & Schmeichel, 2014), the study of perceptual limits within other modalities such as olfaction and audition as a function of avoidance emotions has been largely neglected thus far.

Recently, we have made some first steps to explore perceptual thresholds within these modalities. To clarify some terminology upfront, contrast sensitivity is a concept used mostly in vision. In other modalities, it is more common to use the term *threshold*. A threshold is the minimum amount of physical energy needed to trigger an experience of the stimuli. In daily parlance, one can refer to *threshold* as the reciprocal of *sensitivity*. We will use the term *threshold* to describe findings from modalities other than vision.

Olfaction

One research investigated the effects of negative emotions (manipulated by presenting participants with a series of negatively valenced pictures) and found that negative emotions *increased* olfactory threshold (Pollatos et al., 2007). However, the negative stimuli used were a mixture of several negative emotions (sadness, fear, anger, and disgust) that are related to various motivational orientations. Hence it is unclear which emotions or motivational orientations were responsible

for the effect and, therefore, the study is less relevant for our review on avoidant emotions and perceptual limits.

In Chan, Holland, van Loon, Arts, and van Knippenberg (in-press, Chapter 2), we specifically investigated the avoidant emotions, fear and disgust. We theorized that the improvement of visual contrast sensitivity during disgust (Sherman et al., 2012) may extend to smell sensitivity as well. We tested this hypothesis first by having participants view disgusting, appetizing, or neutral pictures while their olfactory thresholds were assessed with a battery of varying concentrations of the odorant *n*-butanol (Sniffin' Sticks; Hummel, Sekinger, Wolf, Pauli, & Kobal, 1997), which smells like whiteboard marker ink and is commonly used to assess olfactory function. On each trial of the Sniffin' Sticks procedure, participants were presented with a triplet of sticks, of which one contained the odorant and the other two were blanks. The participant's task was to identify the stick that smelled different. The procedure started with participants sniffing target sticks (within triplets) containing a concentration of *n*-butanol way below normal human threshold. If the participant's answer was wrong, the next trial (triplet) would contain a target stick of a higher *n*-butanol concentration. This procedure repeats until a point at which the concentration is high enough such that the participant's answer was correct. When this happened, the next trial would contain a target stick of a lower *n*-butanol concentration, triggering what is called a "reversal point" in the procedure. The procedure continues until a wrong response was given, thereby triggering another reversal. The whole procedure repeats until seven reversal points were obtained. The average value of the last four reversals constituted the olfactory threshold.

The results of our initial two studies (Studies 2.1 and 2.2) showed that participants who were viewing disgust pictures were able to detect scents with lower odorant concentrations compared to participants who were viewing neutral or appetizing pictures. In a subsequent study (Study 2.3), we also included a fear manipulation. We found that both avoidant emotions, disgust and fear, lowered olfactory threshold, and this effect was particularly strong for individuals high in trait disgust sensitivity, the tendency to experience disgust. Interestingly, the latter effect was also found when participants were viewing fearful pictures. Hence, it is possible that avoidant emotions in general lead one to have a lower olfactory threshold.

In subsequent work, we further tested the mechanism underlying this effect. Because both fear and disgust lowered olfactory threshold, it was possible that these emotions induced a general vigilance for odors. We called this the *general vigilance hypothesis*. However it was also possible that threshold was lowered not because of the avoidant component of fear and disgust, but because participants in a negative emotional state were better able to detect an unpleasant scent, which *n*-butanol incidentally was. We called this the *valence-fit hypothesis*. To tease apart these hypotheses, we (Chan, van Dooren, Holland, & van Knippenberg, 2016; Chapter 3) tested thresholds for both *n*-butanol and phenylethanol, which was a positive scent, after a manipulation of disgust, happy, and neutral emotions. We hypothesized that if disgust improves general olfactory sensitivity, then disgust would lower thresholds towards both scents; if disgust improves olfactory sensitivity only to negatively valenced smells, then disgust would not lower thresholds towards phenylethanol. The results revealed that disgust (compared to neutral or happiness conditions) lowered

olfactory thresholds to both *n*-butanol and phenylethanol. From these two sets of studies, we concluded that avoidant emotions lower general olfactory thresholds.

Audition

The approach–avoidance distinction is integral to an understanding of emotion (Elliot et al., 2013). Disgust and fear are both avoidant emotions and both lowered olfactory (Chan et al., in-press; Chapter 3) and visual thresholds (e.g., Phelps et al., 2006; Sherman et al., 2012). In another line of research, we examined whether directly inducing an avoidance orientation would reduce thresholds. We tested this in the auditory domain (Chan, Holland, Hengstler, & van Knippenberg, 2016; Chapter 4). In a series of studies, participants adopted either an arm flexion or extension as a manipulation of approach or avoidance motivational orientation (Cacioppo, Priester, & Berntson, 1993), respectively, while their auditory thresholds were measured in a double staircase paradigm (see Figure 3). This paradigm started with presenting discrete tones that were either clearly audible, or inaudible. In the descending staircase, participants heard an audible tone and responded to it with a mouse click. The next presentation of this tone was then softer. The procedure repeated until participants could no longer hear the tone. This triggered a reversal, where the next presentation of this tone was louder. When this tone became detectable, a reversal occurred again and the next presentation of the tone was softer. A similar procedure occurred in the ascending staircase, which was interwoven with the descending staircase. In the ascending staircase, participants were presented with an inaudible tone that became progressively louder until participants detected it, and

progressively softer when participants failed to detect it. The alternate loud-soft adjustments in both staircases were repeated until a stable threshold was obtained (Cornsweet, 1962; Leek, 2001; Silva, Souza, Bevilacqua, & Lopes, 2011).

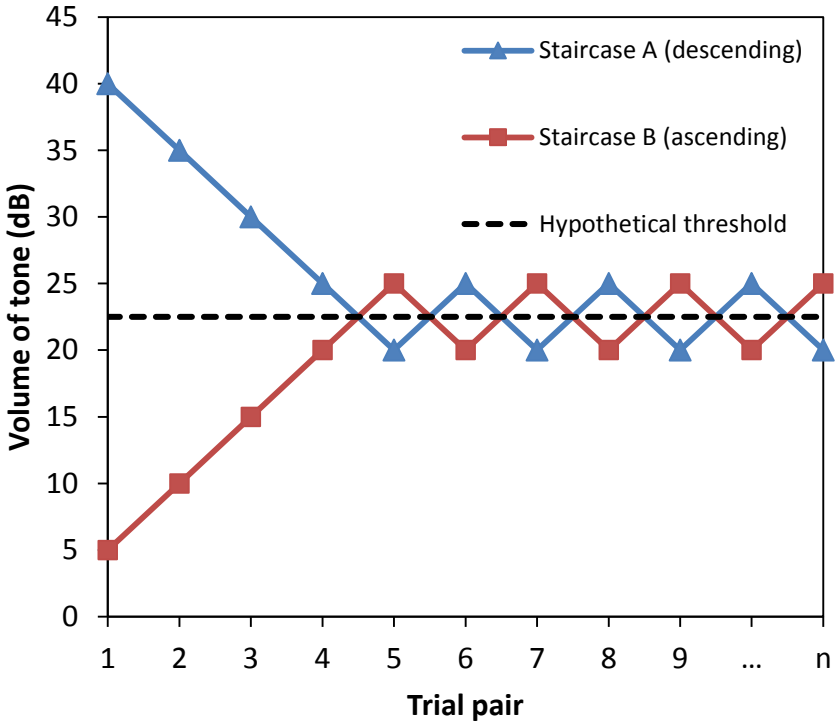


Figure 3. Double staircase procedure.

Our initial two studies in this line of research (Studies 4.1 and 4.2) indicated that individuals under an avoidant motivational orientation displayed a lower auditory threshold to high frequency tones (4000 Hz) but not to low frequency tones (200 Hz, 500 Hz, 1000 Hz). This could be because high frequency tones are both negative and

rare in the environment. Some studies have shown that an avoidant motivational orientation facilitates responses to negative stimuli (Whalen, 1998), whereas others reported such effects for rare stimuli (Foote et al., 1983; Svensson, 1987). Therefore, negativity and mere novelty were both strong candidates to explain our selective findings for motivational orientation to influence auditory threshold. These ideas was further bolstered by our studies (Studies 4.3A and 4.3B) in which indeed our high frequency sounds were more negatively evaluated compared to the lower frequency tones. Furthermore, an analysis of natural sounds (Bradley & Lang, 2007) clearly revealed that sounds with a frequency that is higher than 2000 Hz are rare.

Hence, in follow-up experiments, we investigated the novelty and valence explanations separately. In one study (Study 4.4), we manipulated the novelty of tones by habituating participants to the 4000 Hz tone in the first part of the experiment, and measured the thresholds while participants were in an approach/avoidance motivational orientation in the second part of the experiment. We hypothesized that if avoidant individuals had a lower auditory threshold to high frequency tones because these frequencies were rare, then repeated exposure to these tones would make these tones no longer rare, and hence negating any threshold differences. This, however, did not happen; we did not find an interaction between the motivational orientation and novelty manipulation. At the same time, we should be cautious to fully dismiss the novelty explanation, because in this specific study we did not find a difference between approach and avoidance orientation for the novel 4000 Hz stimuli either.

In the next set of experiments (Studies 4.5A and 4.5B), we tested the valence explanation. We reasoned that if avoidant individuals had a

lower auditory threshold to high frequency tones because these frequencies were negative, then manipulating the valence of neutral tones would be a way to test if valence was the critical factor. We manipulated the valence of the tone, employing a conditioning paradigm in which we paired neutral tones (1000Hz) with positive or negative images in the first part of the experiment, and measured the thresholds while participants were in an approach or avoidance motivational orientation in the second part of the experiment. We found that when neutral tones acquired negative valence, avoidant individuals had a lower threshold for these tones. Hence, we concluded that avoidant motivation orientation lowers thresholds to high frequency sounds because these sounds are negative in valence, but we cannot make strong conclusions about this effect because a meta-analysis across these studies revealed that the effect is weak.

Integrating our findings in olfaction and audition

Do the effects involve merely the negativity of emotions? Approach–avoidance (motivational orientation) and emotional valence (positive vs. negative phenomenological experience) are inextricably intertwined; approach motivation is often linked to positive feelings, and avoidance motivation is often linked to negative feelings (Lang, 1995; Russell & Carroll, 1999; Watson, Wiese, Vaidya, & Tellegen, 1999). Therefore, it may be tempting to conclude that negative emotions in general, whether experienced as a phenomenological state or a reaction to a stimulus, improve sensitivity. However, it may be more fruitful to limit this claim to avoidant emotions, particularly those with high arousal components like fear and disgust. In fact, a recent study (Woods, Philbeck, & Wirtz, 2013) that directly manipulated arousal also found

that arousal lowered visual threshold. Other negative but non-avoidant emotions such as sadness produce different — sometimes mixed — sets of findings. For example, individuals in depressed mood states have a higher threshold in vision (e.g., Dixon & Lear, 1962), audition (Aubert-Khalfa et al., 2010), and olfaction (e.g., Pause, Miranda, Goder, Aldenhoff, & Ferstl, 2001). In clinical cases, researchers have found individuals with depression tend to have higher olfactory thresholds compared to normal control individuals (Schablitzky & Pause, 2014). However, conflicting and null findings have been reported (see Schablitzky & Pause, 2014, for a review) and the underlying neurobiological explanations for clinical cases remain unclear.

When does negativity of the stimuli moderate the effect of avoidant states? In our study on olfaction, disgust lowered threshold for both positive and negative scents, whereas in our studies on audition, avoidant motivational orientation lowered auditory thresholds to high but not low frequency sounds, with the former sounds being more negative. It is tempting to attribute the difference to the experimental situation during smelling vs. hearing. In our olfactory experiments, participants expressed some apprehension when they were asked to smell the sticks. It is possible the prospect of incorporating chemical compounds into the body (Rozin, Haidt, & McCauley, 2008) naturally induced apprehension, regardless of what the valence of the odor was. Sounds, on the other hand, are not chemical molecules but waves, and are not incorporated into the body the same way chemical compounds are. Hence a hearing task is rather innocuous, thereby allowing stimuli valence to exert its effect. This proposition, however, does not hold water alongside studies regarding fear on visual perceptual limits mentioned above (e.g., Bocanegra & Zeelenberg, 2011a; 2011b;

Sherman et al., 2012; Phelps et al., 2006) where the stimuli used were neutral (Landolt circles, gabor patches, black-white shapes, etc.). Therefore, the interaction between stimulus valence and avoidance emotions on perceptual limits remains an open question and warrants more research.

It seems that the effects within olfaction are more robust than that within audition. It is possible that this is because in the evolutionary timescale, olfaction is a more primitive faculty than audition and hence has more direct links to emotion subcortical areas of the brain (Soudry, Lemogne, Malinvaud, Consoli, & Bonfils, 2011; see also Figure 4). However it is admittedly difficult to compare between the two modalities because different manipulations (pictures vs. bodily feedback) were used our research. Future work can shed more light by directly manipulating avoidant emotions when assessing auditory thresholds.

What are the possible mechanisms?

The accrued evidence indicates that avoidant emotions, such as fear and disgust, extend our perceptual capabilities. However, the mechanisms remain poorly understood and in this section, we outline some possible mechanisms. We do not imply that any one of them is necessary or sufficient, in part because they concern different levels of analysis, from distal evolutionary advantages to proximal neural, physiological, and attentional processes.

Evolutionary mechanisms

An increase in perceptual capabilities would seem to have had the evolutionary benefit of allowing an organism to more readily

perceive threat-relevant objects, within its environmental niche. Emotions convey information about the state of the environment (Clore & Schwarz, 2003), relative to one's physiological (Schnall, Zadra, & Proffitt, 2010) or social resources (Schnall, Harber, Stefanucci, & Proffitt, 2008). This information may signal to the organism that something is amiss in the environment, so that being able to take in a wider range of perceptual information to better detect whether something is a threat or not.

Higher level evolutionary theorizing should be compatible with lower levels of analyses, such as those at a developmental or physiological level. If not, either level of theorizing should be revised. For example, although a simple evolutionary perspective would predict that fear increases sensitivity in touch as it does for sight (Phelps et al., 2006). However, psychophysiological perspectives would predict a decrease in tactile sensitivity because fear-related responses tend to cause vascular resistance and decreased skin temperature. Indeed, when investigators (Kelley & Schmeichel, 2014) examined the effects of fear on somatosensory spatial resolution, they found that fear decreased tactile sensitivity, as measured with the two-point discrimination task.[4] A more refined evolutionary perspective could be that fear enhances some forms of sensory perception that are more important in a particular situation (e.g., vision; Phelps et al., 2006) at the expense of other perceptual systems in that particular situation (e.g.

[4] The task involved participants receiving pokes of one point or two points varying between 2-8 mm apart and participants had to report whether two points or one point were presented. The validity of the two-point discrimination task as a measure of spatial resolution has been criticized (Craig & Johnson, 2000; Johnson & Phillips, 1981; Lundborg & Rosen, 2004; Tong, Mao, & Goldreich, 2013).

somatosensory information). In any case, our emphasis is that the evolutionary perspectives should not be used as a broad brush for theorizing, without considering the proximal mechanisms, which we examine next.

Physiological mechanisms

Avoidance emotions may influence perceptual limits by means of physiological changes as well. It is well-known that facial expressions often accompany emotions. In particular the expression of fear is linked to the increase acquisition of sensory input (Susskind, Lee, Cusi, Feiman, Grabski, & Anderson, 2008). Having more sensory input probably increases the chance that some of the inputs will be transduced, and latter interpreted by the relevant cortices. Consider the finding that fear increases contrast sensitivity (Phelps et al., 2006). The contrast sensitivity function (CSF) is a product of optical and neural factors. Optically, the quality of the retinal image (determined by the *modulation transfer function*) strongly depends on pupil size (Artal & Navarro, 1994). Past research has already indicated that fear increases pupil dilation (Bradley, Miccoli, Escrig, & Lang, 2008). Hence, it is possible that fear increases contrast sensitivity via pupil dilation. Because pupil dilation is an indicator of emotional arousal and autonomic activation (Bradley et al., 2008), this might also explain why in disgust – a highly arousing emotion, just like fear – individuals were better able to extract darkened foreground stimuli from lighter backgrounds (Sherman et al. 2012; see also Lee, Baek, Lu, & Mather, 2014). In fact, pupil dilation is also related to the visual system's temporal resolution (Wierda, van Rijn, Taatgen, & Martens, 2012). In addition, there are clear functional concomitants of enhanced pupil

dilation, as pupil dilation has been found to correlate with effort allocation (Rondeel, van Steenbergen, Holland, & van Knippenberg, 2015) and response preparation (Moresi et al., 2008). Hence pupil dilation may be a crucial indicator of the mechanism by which visual limits are extended (Anderson, 2005; Bocanegra & Zeelenberg, 2011a; Phelps et al., 2006; Sherman et al., 2012). Exploring the extent to which physiology can explain other findings, particularly in other modalities, could be a fruitful agenda for future research.

Could physiological arousal be a mediator? Recent animal research has demonstrated that arousal states modulate the responsiveness of neurons during early visual processing (Bezdudnaya et al., 2006; Neill & Stryker, 2010), and the studies that have manipulated fear and disgust certainly suggest so. However, highly arousing food stimuli (Chan et al., in-press; Chapter 3) did not increase olfactory sensitivity, suggesting that it is not arousal per se that is responsible for the extension of perceptual limits. Future studies may wish to include arousal as a covariate to investigate whether arousal plays any role.

The role of attention

Attention serves to modulate sensory processing across all sensory modalities and is integral to producing conscious percepts (Chun, Golomb, & Turk-Browne, 2011). Individuals have limited capacity to process all the stimuli impinging on their sensory system. Attentional mechanisms modulate and sustain focus on whatever information that is most relevant at a particular point in time. Crucially, in all modalities, attention directed towards a stimuli activates areas of the relevant cortices (see Chun et al., 2011, for a review). Recent

research has shown that attention modulates the connectivity between the thalamus (an important sensory relay center) and cortical areas (e.g., Plailly, Howard, Gitelman, & Gottfried, 2008), which may be important for the individuals to consciously analyze a stimulus.

There are two major forms of attention.[5] Exogenous attention refers to bottom-up, stimulus-driven attention where attention is automatically drawn towards a stimulus, such as a flashed stimuli or a presented sound. Endogenous attention, on the other hand, refers to top-down, goal-directed attentional control where attention can be directed voluntarily based on task demands. It is unlikely that exogenous attention is involved when avoidant emotions enhance perceptual limits. Researchers who found fear to increase visual contrast sensitivity have already ruled out the involvement of exogenous attention when they presented visual prompts in the same visual area of their target stimuli (Phelps et al., 2006). Similarly, in the olfactory research by Chan et al. (in-press; Chapter 3), blindfolded participants were given instructions to smell an odorant that was presented right under their nostrils, and such explicit instructions make it unlikely that participants' attention would be directed elsewhere. On the other hand, it is possible that some form of endogenous attention is involved, such as greater interoceptive awareness (Craig, 2003). Fear and disgust are highly visceral emotions. As such, attention may be

[5] We avoid using covert/overt attention because these two forms of attention are valid concepts in sensory systems (e.g., vision) that have a spatial structure. For example, in vision, covert attention can be directed around a visual space without any eye movements. Our work includes olfaction, and there is no evidence to suggest that attention can be shifted between nostrils covertly (Keller, 2011). However, overt spatial shifts of attention are possible in olfaction by head-turning.

drawn toward any visceral bodily reactions. This attention toward the self may also involve greater attention to incoming sensory signals.

Neural mechanisms

Each sensory system has its unique way of transcribing and relaying signals to the relevant cortices. Processes that influence these unique pathways could potentially influence the eventual percept. Vision, hearing, gustation, and somatosensation all have bidirectional projections to the thalamus; olfaction is the only system that does not connect to the thalamus directly (see Figure 4). Conventionally the thalamus was thought to be a relay center for sensory signals, but recent evidence has suggested that it does not merely relay signals, but has modulatory capabilities as well (Lee & Sherman, 2010). Crucially, the amygdala projects to the thalamus and, independently, to the olfactory system. Because the amygdala is involved in emotion processing, it is not surprising that emotions influence perception. But what sort of emotions, what kind of perception, and in what direction? We explore these issues in greater detail next.

Previous research has found that if a stimulus has been fear-conditioned, neural responses to these stimuli become enhanced (e.g., Armony & Dolan, 2002; Li, Howard, Parrish, & Gottfried, 2008). As such, avoidant emotions can be said to amplify incoming sensory signals, much like an electronic amplifier increases the signal-to-noise ratio to produce clear audio recordings. Recall that all signals except olfaction pass through the thalamus, before reaching the sensory cortices either directly, or via the amygdala (see Figure 2). Hence there are two probable proximal mechanisms that could mediate this amplification: the amygdala and the thalamus. If there is only one common amplifier

for all sensory systems (including olfaction), then the amygdala[6] is a more probable candidate than the thalamus because previous research has shown that avoidant emotions causes increases in olfactory sensitivity (Chan et al., in-press; Chapter 2).

The amygdala is a brain region involved in emotion. Some scientists regard danger detection or vigilance as the fundamental role of the amygdala (Freese & Amaral, 2009; Whalen, 1998; see also Armony & LeDoux, 2000). For example, negative stimuli such as fearful faces trigger a stronger BOLD signal in the amygdala than neutral or happy faces (Pessoa, Guiterrez, & Ungerleider, 2002). However, the amygdala is not only involved in emotion processing, it also shares reciprocal connections with many other subcortical areas, including reciprocal connections to the thalamus – the dynamic sensory relay center for taste, vision, audition, and somatosensation – and the olfactory system. Thus, the amygdala not only receives sensory signals, but may also modify them. When neutral visual (Armony & Dolan, 2002), olfactory (Li et al., 2008), or auditory stimuli (Buchel, Morris, Dolan, & Friston, 1998) acquire aversive emotional value via conditioning, these stimuli produce increased responses in the visual, olfactory, and auditory cortical areas, respectively. The enhanced cortical responses are therefore due not only to the sensory features of stimuli, but also to their emotional value. The amygdala is an important modulator of sensory activation, and possibly enhances perceptual acuity by amplifying sensory signals that passes through it (see also Krusemark & Li, 2012; Suslow et al., 2006).

[6] In this review, we do not pinpoint specific amygdala subnuclei because functional MRI studies in humans do not have sufficient spatial resolution to conclusively differentiate which subnuclei could be involved (Whalen, 1998).

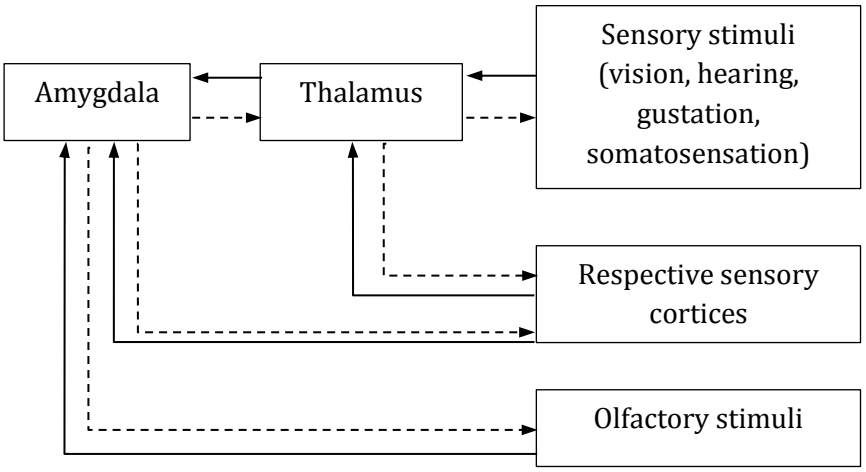


Figure 4. The bidirectional projections of the sensory systems and subcortical areas. Note that the thalamus is connected to the so-called neocortex of vision, audition, gustation, and somatosensation. Olfactory cortex is not neocortex.

Enhanced activity in the sensory cortices is not perceptual experience per se (Ramachandran & Hirstein, 1997), but it makes perceptual experience more probable. We know that observers have lower auditory thresholds to aversively conditioned 1000 Hz tones (Chapter 4). The involvement of the amygdala would make a unique prediction about auditory thresholds during fear. The amygdala is neuronally tuned to high frequency auditory stimuli (Bordi & LeDoux, 1994). Hence if fear influences auditory thresholds, this influence should be most obvious for high frequency sounds. Supporting data come from a recent experiment showing that avoidant motivational states lower auditory thresholds for 4000 Hz tones, but not for 1000 Hz tones (Chapter 4, Studies 4.1 and 4.2).

Is phenomenological experience of the avoidant emotions necessary?

The amygdala is a component involved in the processing of emotional stimuli; it is not a component involved in the feelings per se (Damasio et al., 2000; Reiman et al. 1997; Whalen, 1998; see also Feinstein, Adolphs, & Tranel, 2016). This observation was first made when researchers found that the amygdala was not activated when individuals were recalling emotional states but was activated when emotional stimuli were presented visually (Reiman et al. 1997). Subsequent research also revealed the absence of amygdala activation during the feeling of self-generated happiness, sadness, anger, and fear (Damasio et al. 2000).

These findings lead to a unique prediction. Recall the sensory connections with subcortical regions in Figure 2. If the activation of the amygdala is necessary to potentiate sensory sensitivity, perceptual limits should be extended by emotion only if the emotion is triggered by some external stimuli, not when the emotion is self-generated (e.g., recalled fear). That is, the emotion stems from exogenous and not endogenous sources. In other words, enhanced perceptual capabilities may not necessarily require the phenomenological experience of the emotion. Some of the studies on perceptual limits reviewed here have triggered motivational/emotional states via visual stimuli such as fearful faces (Anderson, 2005; Bocanegra & Zeelenburg, 2011a, 2011b; Phelps et al. 2006; Sherman et al., 2012) or by somatosensory feedback (e.g., Chan et al., in-prep; Chapter 4), neither of which is known to reliably result in phenomenological feelings. The implication is that replication attempts in this area of research with emotion elicitation methods such as recall or vignettes may be futile, not because these

methods are possibly weaker, but because they do not involve the amygdala.

Conclusions and Future Directions

Our senses give us a representation of the external world in which we live. These representations are not only reflections of external reality, but perhaps are also reflections of our internal psychological states. In this review, we have put forward the notion that avoidant emotions extend perceptual limits. Here we have not only outlined several mechanisms at various levels of analysis to guide future research, but we have also showed how our work in olfaction and audition (Chapters 2 – 4) is consistent with our theorizing.

So, do avoidant emotions extend perceptual limits? Based on the available evidence, the answer is "yes," but not without constraints. For example, fear involves increased visual contrast sensitivity but only for low (Phelps et al., 2006) and not for high spatial frequency stimuli (Bocanegra & Zeelenberg, 2009). In addition, there are other kinds of perceptual limits (also Bialek, 1987), but whether they are affected by emotions has not been explored. Here we outline a few examples, and a caveat.

Humans can see light with wavelengths from 380 nm to 750 nm, hear frequencies between 20-20000 Hz, localize sounds with a minimum audible angle (MAA) of 1˚ on the azimuth (Mills, 1958), and discriminate 1 trillion odors (Bushdid et al., 2014). We do not claim that emotions can influence all of these. Consider auditory localization as an example. A small MAA suggests that our auditory localization capabilities are already finely tuned. In combination with head turning (Perrett & Noble, 1997), it can help individuals to visually locate (and

possibly avoid) objects, accurately, and quickly. It is hard to conceive what further advantages an MAA smaller than 1 degree would bestow upon humans. Now compare this to odor and color discrimination abilities. Humans theoretically can discriminate between 1 trillion odors (Bushdid et al., 2014). Would there be a functional advantage to discriminate more than 1 trillion odors? Perhaps not. Might there be benefits to discriminate more than 2 million "colors"? Some species of birds, fish, amphibians, reptiles and insects can see about 100 million "colors" (Jordan, Deeb, Bosten, & Mollon, 2010) so there are probably advantages of such color perception abilities for them, but it is not clear what advantage there would be for humans. Our point is, it may be useful to consider what sort of evolutionary benefits might be conferred on an organism by extending a certain perceptual limit, as well as examining how the process changes during emotions and the possible proximal mechanisms involved.

The evolutionary benefits of avoidant emotions extending perceptual limits are clear, but will approach emotions not achieve the same? In the fairy tale *Little Red Riding Hood*, when the girl questioned the large eyes and nose of her "grandmother" (the hungry wolf in disguise), the "grandmother" replied: "the better to see you", "the better to hear you", and so on. Humans have evolved better physiological features not only to avoid predation but also to approach rewards. As such, psychological mechanisms to enhance detection of rewards may also be present. However in Chan et al. (in-press; Chapter 2), it was clear that showing participants appetitive food pictures did not decrease olfactory thresholds to *n*-butanol. It is possible that approach emotions operate on more specific reward cues, whereas avoidant emotions operate on cues more indiscriminately (Chapter 3). In a

threatening situation, an organism would enhance survival by indiscriminately avoiding cues, but in a safe situation, there is only a limited number of cues that would enable the organism to flourish (e.g., ingestible food). Future directions might wish to consider priming appetitive emotions and assessing olfactory thresholds for specific reward cues such as isomyl acetate (banana scent).

Many important questions remain unanswered. First, to what extent can we expect that avoidant emotions would extend perceptual limits in all modalities? To date, most research in this area has focused on vision; research regarding other modalities has started to emerge only recently. More research from various sensory domains is needed to provide a more conclusive answer. Another deserving question is to what extent, within a particular modality, can we generalize across stimuli? When testing visual contrast sensitivity, for example, existing research has used simple geometric shapes because these stimuli allow excellent experimental control. It remains an open question whether the results can be generalized to socially-relevant stimuli. Perhaps just as important is the question of which perceptual limits would be lowered. Within each modality, there could be multiple perceptual limits (see Appendix). Many other perceptual limits remain unexplored and this review is ripe to highlight opportunities for future research. Clearly more research needs to accrue for us to understand more holistically when and how avoidant emotions extend perceptual limits. We hope that this review is a fruitful step that would guide future research.

Appendix

What are the possible perceptual limits?

Here, within each sensory modality, we first spell out what the possible perceptual limits are (see also Table 1). Note that although there are common concepts (e.g., threshold), some modalities will have unique concepts that apply only to themselves but not to others. This section is intended to be descriptive, not explanatory. Readers interested in the physiological or neural systems that support each system should refer to respective handbooks.

Vision

Within vision, there can be four possible perceptual limits: contrast sensitivity, spatial resolution, temporal resolution, and spectral sensitivity. *Contrast sensitivity* is the ability to differentiate between subtle shades, typically grey shades as in gabor patches. This concept is similar to *threshold*, but threshold in vision has a more traditional definition – the minimal light intensity that evokes a visual experience. *Spatial resolution* (acuity) is the ability to discriminate the smallest gaps present in the optotypes of Landolt shapes (in research setting), or letters using Snellen or Bailey-Lovie charts (in an optometry setting). *Temporal resolution* is the ability to resolve two images as occupying different timespace. For example, in a movie, the eyes technically "sees" sequences of discrete images but because the frame rate is higher than the temporal resolution of vision, we have a "smooth" visual experience of the movie; if the frame rate is lower, we experience "choppy" images. Often, we are not aware of each individual "choppy" images when they appear quick enough serially (*rapid serial visual presentation*). This

unawareness is also known as the *attentional blink*. *Spectral sensitivity* refers to the range of wavelengths (390 nm to 700 nm) that the rods and cones in our eyes can detect, or the so-called "visible" spectrum.

Audition

Within hearing, there can be three possible perceptual limits: threshold, frequency, temporal resolution, and localization. The *threshold* of hearing is the lowest intensity sound that produces an auditory experience. The human ear is tuned to *frequencies* between 20 Hz to 20 kHz; tones outside these ranges are not perceived. The *temporal resolution* of hearing determines whether clicks presented at very quick succession would be perceived as one tone rather than two separate clicks; the fastest temporal resolution found was 10 μsec (Leschowitz, 1971). Auditory localization is the ability to determine where a sound is coming from. The auditory system *localizes* things in space based on the relative loudness between ears (interaural intensity difference) and relative time it takes for a sound to reach one ear before the other (interaural time difference). From these cues, researchers can also calculate the minimum distance between two sound sources on an azimuth for them to be perceived as occupying two different spatial locations (i.e., minimum auditory angle; Mills, 1958). Conceptually, the minimum auditory angle is comparable to the visual system's spatial resolution.

Olfaction

Within olfaction, there can be two possible perceptual limits: threshold and localization. The *threshold* of taste is the lowest concentration of odor molecules that is needed to trigger a smell

sensation. *Olfactory localization* (Porter et al. 2007) is the ability to determine sources of odors in space. Establishing a "minimum olfactory angle," on the other hand, although possible in theory, is not possible in practice because of the erratic nature of molecular movement, even in enclosed spaces (i.e., Brownian motion).

Somatosensation

Within somatosensation, there can be three possible perceptual limits: threshold, spatial, and temporal resolution. Unlike the other sensory systems, there are four primary somatic submodalities: proprioception (the sense of positions of our bodies in space), tactile sensation (the sense elicited by nonpainful stimuli against the body surface), nociception (the sense elicited by noxious stimuli applied to the body), and temperature (the sense elicited by stimuli of a different temperature gradient than the body surface).

Touch *thresholds* are more accurately conceived as touch-pressure detection thresholds. A touch threshold is the smallest amount of force pressed down onto the skin (e.g., using Semme-Weinstein nylon filaments; Weinstein, 1993) that triggers that contact sensation. *Spatial resolution* in touch refers to the ability to resolve distances between two points by touch. This can further be divided into passive touch as in a two-point touch test, or active touch as in reading Braille letters (Lederman & Klatzky, 2009). *Temporal sensitivity* is the ability to judge whether pulses presented on the skin are separated in time.

Gustation

Within gustation, there is one possible perceptual limit: *threshold*, the lowest concentration of tastant molecules needed to trigger a taste sensation.

CHAPTER 2

Disgust and Fear Lower Olfactory Threshold*

Abstract

Odors provide information regarding the chemical properties of potential environment hazards. Some of this information may be disgust-related (e.g., organic decay), whereas other information may be fear-related (e.g., smoke). Many studies have focused on how disgust and fear, as prototypical avoidant emotions, facilitate the detection of possible threats, but these studies have typically confined to the visual modality. Here, we examine how disgust and fear influence olfactory detection at a particular level—the level at which a subliminal olfactory stimulus crosses into conscious perception, also known as a *detection threshold*. Here, using psychophysical methods that allow us to test perceptual capabilities directly, we show that one way that disgust (Studies 2.1– 2.3) and fear (Study 2.3) facilitate detection is by lowering the amount of physical input that is needed to trigger a conscious experience of that input. This effect is particularly strong among individuals with high disgust sensitivity (Studies 2.2–2.3). Our research suggests that a fundamental way in which avoidant emotions foster threat detection is through lowering perceptual thresholds.

* This chapter is based on: Chan, K. Q., Holland, R. W., van Loon, R., Arts, R., & van Knippenberg, A. (in-press). Disgust and fear lower olfactory threshold. *Emotion*.

We rely on our sense of smell more often than we realize (Doty, 2003; Herz, 2008). Indeed, when olfactory abilities are compromised, up to 75% of individuals have problems identifying spoiled food (Miwa et al., 2001; Temmel et al., 2002) and, consequently, up to 50% end up accidentally consuming it (Bonfils, Faulcon, Tavernier, Bonfils, & Malinvaud, 2008; Santos, Reiter, DiNardo, & Costanzo, 2004). Although human olfaction abilities are weak compared with those of some other animals such as dogs and rabbits, we are still able to recognize thousands of different scents, and we are sensitive to some compounds at minute concentrations. Enhanced smell sensitivity, the lowering of olfactory thresholds, may ensue from clinical disorders (Doty & Kimmelman, 1986) such as Addison's disease, pituitary tumor growth, as well as from genetic polymorphisms (Keller, Zhuang, Chi, Vosshall, & Matsunami, 2007) and biochemical factors (Menashe et al., 2007; Mourad, Lejoyeux, & Adès, 1998; Navarrete-Palacios, Hudson, Reyes-Guerrero, & Guevara-Guzmán, 2003). However, whether psychological states also impact olfactory thresholds has rarely been investigated. In fact, textbooks on olfactory psychophysics (e.g., Mather, 2011) and otorhinology (Hawkes, 2009) usually focus on how structural properties of physical stimuli (e.g., isomerism) influence thresholds, but have thus far neglected possible psychological influences. Here, we examine two avoidant emotions, disgust and fear, that may have the strongest influence on olfactory thresholds.

Avoidant Emotions and Perceptual Vigilance

Disgust and fear are prototypical avoidant emotions. They share functional and conceptual features, despite having different facial expressions, physiological markers (Ekman, Levenson, & Friesen, 1983;

but see Barrett, 2006), appraisal antecedents (Clore & Huntsinger, 2007), and qualia. Disgust is a phenomenological feeling of revulsion at the prospect of incorporation of an offensive object (Rozin & Fallon, 1987). This incorporation can be through the mouth (eating spoilt food), nose (airborne particles from someone's sneeze), or skin (touching poop). Disgust is a key emotion in the behavioral immune system (Haidt, 2008; Oaten, Stevenson, & Case, 2009; Rozin & Fallon, 1987; Schaller & Duncan, 2007), a suite of psychological mechanisms and behavioral responses to prevent infection. One way in which infection is prevented is for the perceptual system to be "comprised of mechanisms designed for detection [of pathogenic intruders]" (Schaller & Duncan, 2007, p. 296). Fear is the phenomenological feeling that one's body could be threatened or harmed in some way. Fear is a key emotion in the human threat management system (Neuberg, Kenrick, & Schaller, 2011), which comprises a constellation of mechanisms (especially the amygdala) that are sensitive to cues about possible threats and the stimuli that predict their occurrence (LeDoux, 1998). Hence, functionally, both disgust and fear enhance vigilance and motivate behavioral avoidance (Schaller & Duncan, 2007). Beyond functional similarities, some scholars have even argued that physical disgust—we do not examine moral disgust in this article—is conceptually similar to fear (S. W. S. Lee & Ellsworth, 2013). In addition, the clinical literature suggests that disgust sensitivity predicts contamination fears (Olatunji, Sawchuk, Lohr, & de Jong, 2004), and others have claimed that disgust elicitors can be characterized by their ability to elicit fear of oral incorporation (Marzillier & Davey, 2004).

One of the functional benefits of avoidant emotions is that they enhance perceptual vigilance at various levels. For example, negative

words are more likely to be correctly classified as negative when they are flashed quickly (Dijksterhuis & Aarts, 2003; see also Labiouse, 2004; and Dijksterhuis, Corneille, Aarts, Vermeulen, & Luminet, 2004); faces paired with negative social information lead to greater visual dominance than faces paired with positive social information (Anderson, Siegel, Bliss-Moreau, & Barrett, 2011); individuals with specific clinical phobias display greater cortical activity and attentional biases when confronted with their feared objects (see Richards, Benson, Donelly, & Hadwin, 2014, for a review). Furthermore, when primed with fear, (a) people rotate mental images faster (Borst, 2013), implying quicker object recognition (Jolicoeur, Corballis, & Lawson, 1998); (b) have better visual spatial acuity (Bocanegra & Zeelenberg, 2009, 2011a); and (c) faster temporal resolution (Bocanegra & Zeelenberg, 2011b).

Disgust and/or fear have also been found to affect a particular aspect of perceptual vigilance, *contrast sensitivity*. Contrast sensitivity concerns the difference in luminance between the target and the background that is required to see a target reliably (Pelli & Bex, 2013). In one set of studies, Phelps, Ling, and Carrasco (2006) found that individuals are more accurate in judging the orientation of faint-gray gabor patches when these stimuli were preceded by fear (vs. neutral) faces. In another study, Sherman, Haidt, and Clore (2012) found that individuals high in disgust sensitivity have better visual contrast sensitivity when individuals were primed with disgust stimuli (e.g., trash can). Interestingly, Sherman and colleagues also showed similar lower contrast thresholds for participants who were primed with fear pictures (see also Phelps et al., 2006). These and other studies reviewed thus far reveal a common theme: Avoidant emotions enhance perceptual processing, which is functional because the emotions

increase the chances that an encountered target becomes detected, identified, and, ultimately, for appropriate behaviors to be enacted (Keller, 2014; see also Stevenson, 2009a). However, these studies have examined only vision, whereas enhanced perceptual vigilance should extend beyond vision. In the current research, we examine the influence of disgust and fear, as two particular avoidant emotions, on olfactory threshold, the lowest amount of physical input that is needed to trigger a conscious experience of that input (Fechner, 1860/1966).[7] The main reason behind this particular proposed extension is that some of the functions served by disgust and fear fit well with that of olfaction. Next we examine each separately.

The Overlapping Functions of Olfaction, Disgust, and Fear

The functions of disgust and fear fit well with some of the main functions of olfaction. Numerous attempts have been made to identify and categorize the functions of the human olfactory system. Smells carry information about substances, and one important function of olfaction is to provide information about the chemical composition of substances before we come into closer contact with them.

In one prominent analysis, Stevenson (2010) classified the functions of olfaction as relating to (a) ingestion, and (b) avoiding environmental hazards.[8] Disgust plays an important role in shaping

[7] This definition is similar to that of contrast sensitivity. Conceptually, for any target signal to be detected, it must be contrasted against a background signal (e.g., other background odors, neural noise). Traditionally, *contrast sensitivity* is a term used only in vision because the word "contrast" refers to luminance (Pelli & Bex, 2013), whereas *threshold* is a term used for any modality (including vision, e.g., "contrast threshold sensitivity"). Mathematically, threshold is the reciprocal of sensitivity.
[8] Stevenson (2010) also identified social communication as the third function of olfaction. Others have claimed navigation as the primary function of olfaction

food choices (Rozin, Haidt, McCauley, & Imada, 1997). Researchers showed that odors are often used (along with other cues) to judge whether something should be considered a food or not before (Rozin, Fallon, & Augustoni-Ziskind, 1985) or after (through retronasal olfaction; Stevenson, 2009b; Verhagen & Engelen, 2006) ingestion. For example, some individuals reject eating cheese because of its peculiar smell (before or after ingesting it), although cheese is safe for consumption. Aside from ingestion, odors may also signal the presence of two categories of environmental hazards. The first category relates to microbial threats (e.g., organic decay, feces, vomit), for which disgust plays a strong role. Indeed, exposure to these threats often produces strong feelings of disgust. Therefore, an important function of disgust is to reduce the probability of physical contact with pathogens (Tybur, Lieberman, Kurzban, & DeScioli, 2013; see also Curtis, Aunger, & Rabie, 2004, and Curtis & Biran, 2001). The other category relates to nonmicrobial threats (e.g., predators, smoke, gas leaks), which are more strongly linked to fear. Because disgust, fear, and olfaction share functional features, and because disgust and fear are avoidant emotions, we hypothesized that disgust and fear lower olfactory threshold.

To our best knowledge, research has not yet shown how disgust and fear experiences relate to olfactory sensitivity, although there are common links between disgust, fear, and olfaction based on their respective functions. We acknowledge that there have been some claims that disgust increases olfactory sensitivity (Rozin et al., 1986; Skarlicki, Hoegg, Aquino, & Nadisic, 2013). However, the conceptualization of *sensitivity* was often muddled with emotional reactivity (the "Yuck!"

(Jacobs, 2012). But because these functions are not central to our discussion on disgust and fear, we do not discuss them here.

response) or cognitive judgments of stimulus intensity ("How intense is this smell?") rather than the kind of psychophysical perceptual capability (i.e., detection thresholds) that we seek to examine in this research. Thus, it is still unclear whether disgust influences olfactory sensitivity.

The Present Research

Using psychophysical methods, we performed three experiments to test the effect of avoidant emotions on olfactory detection threshold. In the first two experiments, we sought to establish whether disgust influences olfactory threshold. We chose to examine disgust first because the function of disgust seems to fit more closely with the nature of olfaction. Humans detect smells mostly at short ranges, usually at distances shorter than a couple of meters. Certainly, smells produced by hazards such as pathogens cannot travel far distances (Tybur et al., 2013), although there are exceptions, like big fires. These are the environmental conditions that typically may elicit disgust (note that here we are not concerned with moral disgust). At longer distances, sound and sight may, at least for humans, be more important as primary sources of information concerning avoidance. Thus, for the elicitation of fear, vision and hearing may be even more informative than smell. In short, that is why we presume that there could be a more intimate link between smell and disgust than between smell and fear. Therefore, the effects of disgust on olfaction threshold will be studied first.

In the third experiment, we also tested the effect of fear on olfactory thresholds to investigate the relative influence of disgust and fear on olfaction sensitivity. Finding that disgust (but not fear)

decreases olfactory threshold would indicate a function-specific influence; that is, emotions influence sensory processes only when the functions of the emotion most closely match that of the sensory modality. However, if fear likewise decreases olfactory threshold, this would point to a more generic view that avoidant emotions decrease threshold. Such a view is compatible with the behavioral immune system because the behavioral immune system can itself be conceptualized as part of a larger "human threat management system" (Neuberg et al., 2011).

Study 2.1

In a within-participants manipulation, participants were shown pictures to induce the emotions disgust, appetite, and a neutral emotional state. Appetite was chosen as a comparison condition to ensure that any effect on threshold is specific to disgusting food, not just food in general.

Method

Participants and Design

Thirty-nine participants[9] (M_{age} = 24.3 years, SD_{age} = 7.3) took part in an experiment allegedly about the "effects of odors on memory." They received either course credits or €7.50 (US$8.50) as remuneration. Participants reported having no smell abnormalities on the day of testing, and they complied with our requirements of not smoking, eating, or drinking (except plain water) 2 hr before the experiment.

[9] For all experiments, we originally aimed to recruit at least 34 participants, based on 80% power, $\alpha = .05$, $d = 0.5$, in a within-participants design, and until the week for conducting the experiment was over (stopping rule).

Emotion was manipulated in blocks as a within-participants factor, with the neutral condition always as the first block administered, and the order of the two other blocks was counterbalanced. The design was a 3 (emotion: disgust vs. appetite vs. neutral) × 2 (order of emotion condition: appetite as second block and disgust as third block vs. disgust as second block and appetite as third block) design. The latter factor was between participants.

Setup and Procedure

The physical setup is illustrated in Figure 1. Participants sat front-facing the monitor (A) and experimenters sat at (B). This configuration ensured that experimenters were blind to the condition because they could not see what the current stimulus on the participants' screen was. On the left (C), the full battery of Sniffin' Sticks (Hummel, Sekinger, Wolf, Pauli, & Kobal, 1997), which consists of the threshold, discrimination, and identification sets, were displayed. Only the threshold set was tested. Because the cover story was about the "effects of odors on memory," participants would expect many odors to be tested. Therefore, in order to bolster the cover story, the discrimination and identification sets were also present to give the impression that different smells were being tested.

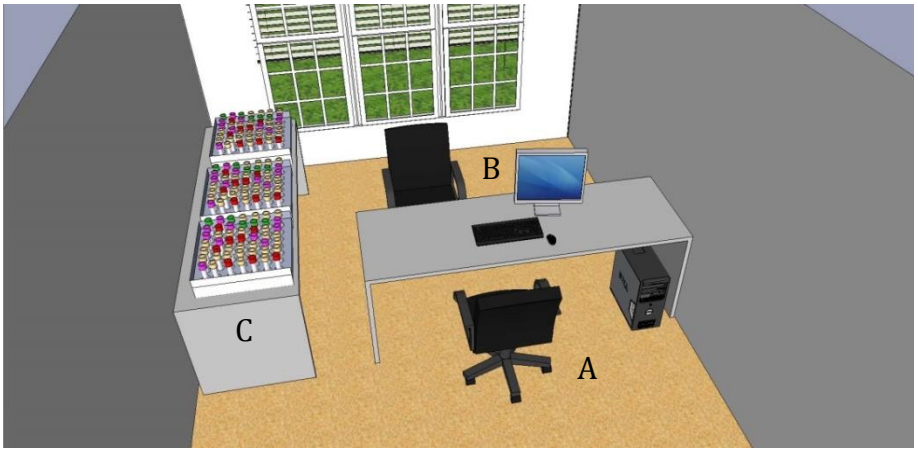


Figure 1. The physical setup of the experiment. Participants sat at A, facing the monitor, while the experimenter sat at B. This configuration ensured that the experimenters could not see what the participant was seeing on the monitor. Sniffin' Sticks were placed at C.

While assessing their olfactory threshold, we manipulated participants' emotional state by showing emotion-inducing pictures of rotten food (35 disgusting pictures), palatable food (32 appetite-inducing pictures), or office stationery (33 neutral pictures). Participants wore their blindfolds whenever they had to sniff the sticks, and took them off when they had to view the pictures. A separate sample of 20 participants validated that the disgust stimuli were more disgusting than the neutral stimuli, paired samples $t(19) = 8.17$, $p = .001$, and the palatable food stimuli were less disgusting than the neutral stimuli, paired samples $t(19) = 2.28$, $p = .03$. Hence, this is strong evidence that our emotion manipulation was successful in the actual experiment (see also the pilot test in Study 2.3).

We followed Hummel et al.'s (1997) procedure closely. At the start of each block, the experimenter let participants sniff Stick #14, a

concentration way above a normal person's threshold, and told the participant that this was the quality of the scent they had to identify. The rest of the procedure is outlined in Figure 2. On each trial, two pictures were shown (each for 3 s), followed by two rounds of olfactory threshold assessment (Pollatos et al., 2007) using the Sniffin' Sticks (see Figure 3). The threshold battery of the Sniffin' Sticks consists of 16 triplets of smell tubes. Each triplet includes one tube containing a target odorant (*n*-butanol) in progressive dilution steps of 2, starting from a concentration of 0.04 *n*-butanol (Stick #1) to 1.2×10^6 (Stick #16) *n*-butanol.[10] On each round of the threshold assessment, participants were presented with three sticks from the same triplet in random order. Only one of the sticks (the target stick) contained the odorant, whereas the other two sticks were blanks. Participants had to indicate which of the three sticks smelled differently. In verbatim, our script was as follows: "This is Stick 1. [Participant sniffs once.] This is Stick 2. [Participant sniffs once.] This is Stick 3. [Participant sniffs once.] Which smells different: Stick 1, 2, or 3?"

If the response was incorrect, the next triplet would contain a target stick of a higher odorant concentration. On subsequent triplets, the target stick's odorant concentration increased step-by-step until a correct identification occurred. In that case, the next triplet contained a target stick of lower concentration (a reversal of the staircase). A subsequent correct response would lead to further lowering of the target stimulus concentration, whereas an incorrect response would be followed by an increase of concentration (a new reversal). This procedure was repeated until seven reversal points were obtained,

[10] The general equation is $y_k = 0.04(2^{1-k})$, where y is the concentration of *n*-butanol at dilution step k.

which concluded one experimental block. The mean of the last four staircase reversal points constituted the threshold measure. Scores ranged from 1 (*lowest sensitivity/highest threshold*) to 16 (*highest sensitivity/lowest threshold*). The assessment lasted about 10 min on average.

When a block ended, two tasks followed: (a) a memory test, which helped bolster the cover story; and (b) a filler task. In the memory test, a collage of 25 pictures was presented and participants had to indicate which pictures had not been presented earlier. In the filler task, participants had to identify faint numbers by pressing the corresponding number on their keyboard. The numbers were presented against a white background and had starting RGB values of 255, 255, 255 that progressively darkened at -1 RGB/s. The task lasted 5 min. This task was initially also intended to be a conceptual replication of Sherman et al. (2012). However, because the digits could not be incrementally darkened consistently at -1 RGB/s (sometimes the RGB decrements took more than 1 s), the results of this task have poor construct validity and will not be published. Nevertheless, we retained this filler task in subsequent experiments because it served its primary purpose as a filler task well.

Demographic information (age, sex, medical olfactory-related information) was gathered at the end of the experiment. Participants were finally thanked and fully debriefed.

Results

The olfactory threshold data were subjected to a 3 (emotion: disgust vs. appetite vs. neutral) × 2 (order: appetite vs. disgust as second block) mixed analysis of variance (ANOVA). There was a main

effect of Emotion, $F(2, 74) = 10.41$, $p = .001$, $\eta_p^2 = .22$. Posthoc tests revealed that the threshold in the disgust condition was lower compared with the neutral condition, $t(38) = 4.41$, $p = .001$, $d = .71$, and appetite condition, $t(38) = 3.24$, $p = .003$, $d = 0.52$. Thresholds in the neutral and appetite conditions did not differ significantly, $t(38) = 0.23$, $p = .98$, $d = .01$. Results are presented in Table 1. We also found a main effect of order, $F(1, 37) = 4.89$, $p = .03$, $\eta_p^2 = .12$, in which thresholds of all blocks were lower in Order 1 (appetite as second block) than in Order 2 (disgust as second block), despite random assignment. Importantly, there was no significant two-way interaction between order and emotion, $F(2, 74) = .28$, $p = .76$, $\eta_p^2 = .008$, implying that order did not affect the contrasts between the emotion conditions. Separate tests of the emotion condition effects within order conditions revealed that the effect was significant within each order (both $ps < .05$).

Discussion

We obtained initial evidence that disgust lowers olfactory threshold, and this effect is not simply because of seeing food-related stimuli. Although a main effect of order was found, order of emotion conditions did not affect our main finding concerning the effect of disgust on olfactory thresholds. Two potential alternative interpretations of the findings of Study 2.1 should be mentioned. First, the neutral block always being first may have compromised the obtained effect (e.g., because of learning or habituation effects). It is therefore important to counterbalance the order of experimental conditions. Second, although the experimenters could not see the primes on participants' monitor during the experiment, it is possible that participants' facial or vocal cues revealed the conditions

participants were currently in. This knowledge could trigger a bias in the experimenters, who could then, consciously or not, have altered their way of executing the olfactory test (e.g., by presenting target sticks for longer periods or closer to the nostrils). In our second experiment, we aimed to rule out both alternative explanations.

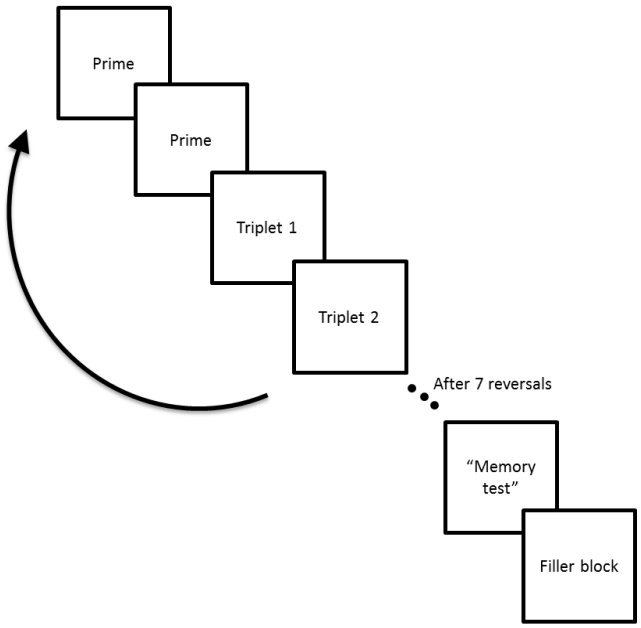


Figure 2. Outline of procedure. Participants' olfactory thresholds were assessed intermittently during the emotional manipulation in a two-picture primes followed by two runs of the threshold triplets procedure. This procedure was repeated until a stable threshold was reached. Thereafter, to allow for a period of rest, an alleged memory test and a filler task were administered.

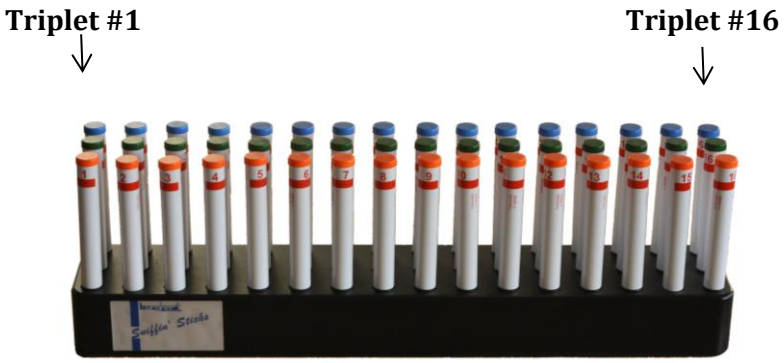


Figure 3. The Sniffin' Sticks threshold battery. The Sniffin' Sticks threshold battery consists of 16 ordered triplets of sticks. Each triplet is comprised of one stick with the target odorant (*n*-butanol) and two sticks with neutral odorant. While blindfolded, participants have to discriminate between the odorous stick (red) and the neutral ones (green and blue), starting with Triplet #16. The target odor concentration doubles across each dilution step. At a certain dilution step, the target odorant would cross a sensory threshold and become just distinguishable from the neutral odorants. The concentration of the target odorant is the weakest in Triplet #16 and strongest in Triplet #1. The lowest dilution step at which participants can consistently discriminate the target from the blanks is the threshold.

Study 2.2

In this experiment, we counterbalanced the order of the neutral and disgust blocks, and videotaped the session in order to investigate whether target sticks were presented for longer periods or closer to the nostrils during the disgust blocks. Because disgust primes may be especially influential for individuals high in disgust sensitivity (Sherman et al., 2012)—the tendency to experience disgust (Olatunji et al., 2007)—we added disgust sensitivity (Disgust Scale–Revised; DS-R; Haidt, McCauley & Rozin, 1994, modified by Olatunji et al., 2007) as a predictor.

Table 1.
Mean Dilution Step (SDs) by Condition

	Neutral	Appetite	Disgust
Order 1: Neu→App→Dis	6.50 (1.68)[a]	6.38 (1.98)[a]	7.99 (2.28)[b]
Order 2: Neu→Dis→App	7.69 (1.41)[a]	7.83 (2.63)[a]	8.84 (1.93)[b]
Average across Orders	7.11 (1.66)[a]	7.18 (2.25)[a]	8.42 (2.12)[b]

Note. Means that do not share the same superscript within a row differ significantly at $p \leq .05$. Neu = neutral; App = appetite; Dis = disgust.

Method

Participants and Design

Thirty-nine participants (M_{age} = 21.7; SD_{age} = 6.3) participated for course credits or €5 (US$5.60). The design was a 2 (emotion: disgust vs. neutral) × 2 (order: disgust first vs. neutral first) × Disgust Sensitivity (continuous factor) mixed-participants design, with Emotion as the within-participant factor and Order and Disgust sensitivity as between-participants factors.

Procedure

The procedure was identical to that of Study 2.1 except for four aspects. First, the appetitive block was removed from the design. Second, the order of the neutral and disgust blocks were now counterbalanced. Third, a video recorder was placed at the left side of the participants' face (90° angle) at 1.5 m distance in order to record

duration and distance of target stick presentation. Fourth, participants completed the Dutch version of the DS-R (Van Overveld, de Jong, Peters, & Schouten, 2011) after the filler task of the last experimental block. The overall alpha reliability of the questionnaire was .85.

Results

The threshold data were subjected to a 2 (emotion: disgust vs. neutral) × 2 (order: disgust first vs. neutral first) × Disgust Sensitivity (continuous) mixed ANOVA. The analysis revealed a main effect of emotion, replicating the findings of Study 2.1, such that the mean threshold was lower in the disgust than in the neutral condition, $F(1, 37) = 4.60$, $p = .03$, $\eta_p^2 = .11$. This effect of emotion was qualified by an interaction with disgust sensitivity, $F(1, 37) = 6.51$, $p = .01$, $\eta_p^2 = .15$. Results are plotted in Figure 4. Compared with the neutral condition, planned contrasts revealed that thresholds in the disgust condition were lower for individuals high in disgust sensitivity (+1 *SD*; $p = .003$), but did not differ for those low in disgust sensitivity (-1 *SD*; $p = .64$). There was no main effect of disgust sensitivity, $F(1, 37) = .02$, $p = .87$, $d = .001$. The Emotion × Order × Disgust sensitivity interaction was not significant, $F(2, 36) = 3.30$, $p = .07$, $\eta_p^2 = .08$. Although this interaction failed to reach significance, we nevertheless probed further in view of its relevance to the alternative interpretation of the neutral condition always being first in Study 2.1. When disgust was the first block (Order 1), there was a marginal effect of emotion, $F(1, 21) = 4.10$, $p = .06$, and a significant Emotion × Disgust sensitivity interaction, $F(1, 21) = 4.83$, $p = .04$. Hence, the neutral condition always being first could not have been responsible for the fact that we found a lower olfactory threshold in the disgust condition compared with the neutral condition in Study

2.1. However, when neutral was the first block (Order 2) in Study 2.2, there was no main effect of emotion (as we obtained in the same order in Study 2.1), and neither was there an Emotion × Disgust sensitivity interaction, *F*s(1, 14) < 1. The nonsignificant main effect of Emotion in Order 2—the very order we found a main effect of Emotion in Study 2.1—was likely because participants in Order 2 had lower disgust sensitivity scores (M = 2.82, SD = .63) than those in Order 1 (M = 3.25, SD = .40), $t(37) = 2.40$, $p = .02$.

For the video coding, eight participants withdrew their consent for the video recording and two footages were lost because the video recorder overheated during the session. For the remaining footages, two coders (an independent research assistant not involved in running the experiment and the first author) independently coded all trials on two indices: (a) the duration each stick was under the nostril (the coders read off Windows Media Player's "elapse timeline" the number of seconds between the moment each stick was under participants' nostrils and the time it was taken away), and (b) the distance of each stick from the nostril (coders used a ruler to measure the screen distance between the tip of the stick and the nostril). Between emotion conditions, no significant differences were found for duration, $F(1, 28) = .17$, $p = .68$, or distance, $F(1, 28) = .47$, $p = .50$. Disgust sensitivity also did not interact with either duration or distance between the emotion conditions, *F*s(1, 28) = .60, $p = .64$. Therefore, our results were unlikely because of experimenter biases.

Discussion

With a counterbalanced disgust–neutral block order, we found that priming disgust lowers olfactory thresholds, particularly among

individuals who have high disgust sensitivity. Importantly, order of emotion block (i.e., the neutral block always being first in Study 2.1) could not have caused the emotion effect, because in Study 2.2 we obtained the same effect with the disgust block being first. Unexpectedly, the disgust effect observed in Study 2.1 (i.e., lower olfaction thresholds with disgust primes than with neutral primes) was not replicated in Study 2.2 with the neutral block measured first. We aim to replicate the latter effect in Study 2.3. Considering the absence of effects of emotion conditions on duration and distance of target stick presentations in our video footages, there was no evidence of experimenter biases in the reported effects of emotions on olfactory thresholds. In Study 2.3, we sought to replicate our main findings again, and also to explore the generality of the disgust-threshold effect to another emotion: fear.

Study 2.3

Disgust is an avoidant emotion that has evolutionary roots in ingestion and avoiding environmental hazards (Stevenson, 2010). Is disgust capable of lowering olfaction thresholds because of its unique relation to smell, or does it share this capability with other avoidant emotions, such as fear? Even though disgust and fear may have different qualia, they are conceptually (S. W. S. Lee & Ellsworth, 2013; Marzillier & Davey, 2004; Olatunji, Haidt, McKay, & David, 2008) and functionally (Schaller & Duncan, 2007) related, and also share similar neurological substrates (Klucken et al., 2012). Hence, in this experiment, we contrasted disgust with fear and neutral emotion.

Method

Participants and Design

Thirty-seven participants (M_{age} = 25.9, SD_{age} = 7.1) participated for course credits or €7.50 (US$8.50). The design was a 3 × 2 design, with Emotion (disgust vs. fear) as a within-participants factor, and Order (disgust vs. fear as second block) and Disgust Sensitivity (continuous factor) as between-participants factors. As in Study 2.1, the neutral block was first.

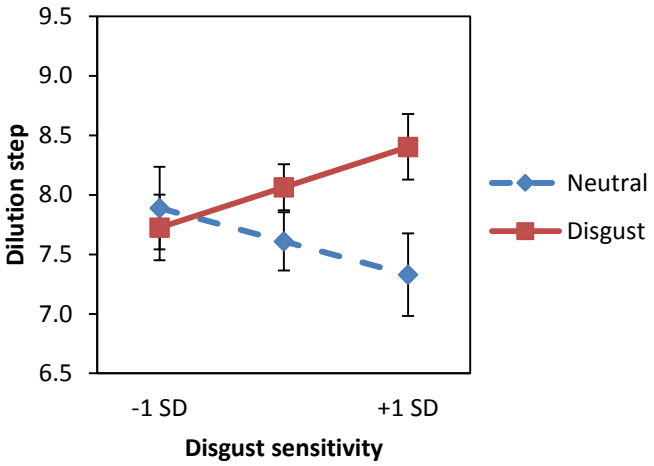
Materials and Procedure

The materials used for the disgust and neutral conditions were identical to those of Studies 2.1 and 2.2. The overall alpha reliability of the DS-R was .84. The neutral block was administered first, and the order of the other two blocks was counterbalanced. To induce fear, we presented pictures of fear stimuli (e.g., gunpoint). Thirty-seven fear pictures were used. A pilot test with a separate sample of 27 participants rated fearful, disgust, and neutral pictures on fear, pleasantness, and arousal. The fear pictures elicited greater fear, $F(2, 26) = 37.2$, $p < .001$, and were less pleasant, $F(2, 26) = 16.8$, $p < .001$, than the disgust pictures, which in turn elicited more fear than the neutral pictures, $F(2, 26) = 12.04$, $p = .002$, and were less pleasant than the neutral pictures, $F(2, 26) = 120.1$, $p < .001$. In addition, fear pictures did not lead to differences in arousal from the disgust pictures, $F(2, 26) = .46$, $p = .50$, although both of them elicited more arousal than neutral pictures, $F(2, 26) = 6.88$, $p = .01$. Hence, our emotion induction was successful.

Results

The threshold data were subjected to a 3 (emotion: disgust vs. fear vs. neutral) × 2 (order: disgust vs. fear as second block) × Disgust Sensitivity (continuous) mixed ANOVA. There was a main effect of emotion, $F(2, 72) = 5.79$, $p = .005$, $\eta_p^2 = .14$. Planned contrasts revealed that disgust lowered olfactory threshold compared with neutral ($p = .002$, $d = 0.55$). Fear, compared with neutral, also lowered olfactory threshold ($p = .05$, $d = 0.33$), whereas thresholds in the disgust and fear condition did not differ ($p = .22$, $d = .21$). In addition, this main effect was qualified by an interaction with disgust sensitivity, $F(2, 70) = 3.23$, $p = .04$, $\eta_p^2 = .08$. Individuals low in disgust sensitivity (-1 *SD*) did not differ in their threshold as a function of emotion (*p*s > .23), whereas the disgust and fear primes increasingly lowered thresholds as disgust sensitivity increased (see Figure 4B), such that for individuals high in disgust sensitivity (+1 *SD*), thresholds after disgust and fear primes significantly differed from neutral (both *p*s < .001). No effects involving order or disgust sensitivity were found (*F*s < 2.34, *p*s > .11). Nevertheless, we further investigated whether disgust thresholds were lower in either order and found that, like in Study 2.1, disgust thresholds were lower in either order (*F*s > 4.42, *p*s < .05).

A



B

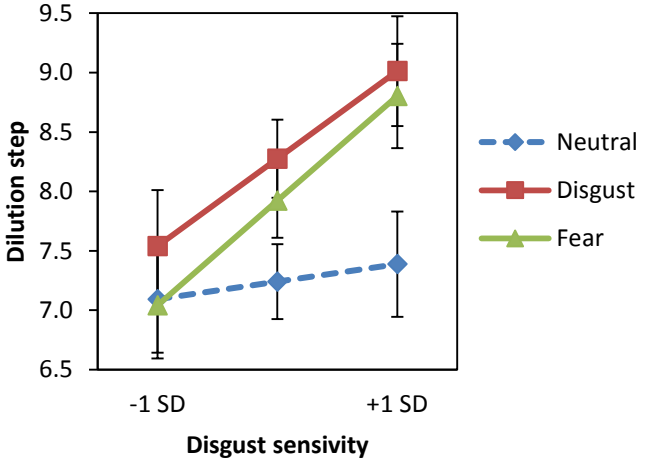


Figure 4. Mean (*SD*) dilution step at threshold value as a function of emotional manipulation in Studies 2.2 (Panel A) and 2.3 (Panel B). Higher dilution steps scores imply lower thresholds. Error bars represent standard errors.

Discussion

We again found that disgust lowered olfactory threshold, particularly for individuals with high disgust sensitivity. Similar effects on threshold were observed in the fear condition. This is probably because disgust and fear are both avoidant emotions—both promote vigilance in the organism. Furthermore, disgust sensitivity correlates strongly with trait anxiety and specific fears (e.g., McDonald, Hartman, & Vrana, 2008; Muris, Merckelbach, Schmidt, & Tierney, 1999).

Although it is unsurprising that disgust sensitivity moderated the effect of disgust on threshold, it may seem strange that disgust sensitivity also moderated the effect of both on olfactory threshold. One possibility is that disgust sensitivity—as a theoretical construct—relates strongly to anxiety and specific fears (McDonald et al., 2008; Muris et al., 1999). Trait anxiety can also modulate the effect of disgust primes on brain activity (Schienle, Schäfer, Stark, Walter, & Vaitl, 2005). Because of the shared variances, functionality, and conceptualization between disgust sensitivity and trait fear, it may not be surprising that disgust sensitivity also interacted with fear primes. The second possibility is that the DS-R was not solely measuring disgust but was also measuring general threat sensitivity. This is because (a) the DS-R contained items that do not straightforwardly relate to disgust (e.g., aversion to walking through graveyards), (b) the labels of the scale asked participants how "anxious" or "bothered" they were by certain events, and (c) the DS-R are more strongly related to neuroticism and emotionality (Olatunji et al., 2008). To pinpoint the exact role disgust sensitivity plays, future research may use other scales that also measure disgust sensitivity (e.g., the three-domain Disgust Scale; Tybur et al., 2009).

General Discussion

In sum, we found that disgust lowered olfactory thresholds (Studies 2.1–2.3). We found similar effects of fear (Study 2.3), probably because both fear and disgust are avoidant emotions tuned toward perceptual vigilance (see also Sherman et al., 2012). The threshold detection advantage in neutral versus disgust states across all experiments is $2^{0.94} = 1.92$; for neutral versus fear, it is $2^{0.70} = 1.62$ (see Supplementary Materials S1 and S2). Furthermore, these effects are particularly evident for individuals with high disgust sensitivity and absent among individuals with low disgust sensitivity. Our findings are important because previous research has postulated (e.g., Levenson, 1999), but not investigated, the link between disgust and perceptual sensitivity (except Sherman et al., 2012). At a more abstract level, because disgust is a key emotion behind the behavioral immune system, we have also shown that one way in which the behavioral immune system (Schaller & Duncan, 2007) works in detecting threats is by altering fundamental perceptual capabilities. Extending beyond the behavioral immune system, because fear is a key emotion in the human threat management system (Neuberg et al., 2011), we have also shown a part of how the human threat management system works.

One might wonder whether there is a theoretical contradiction between our conclusions on disgust increasing olfactory sensitivity and the functions of disgust facial expressions (e.g., wrinkling nose, narrow brows), which serves to restrict further inputs (D. H. Lee, Mirza, Flanagan, & Anderson, 2014). However, the qualia of an emotion often outlast its facial expression. Therefore, any facial expression causing the restriction of input—which inevitably increases thresholds—may happen only upon the initial encounter with the trigger when the

expression is present. Over an extended period of time (e.g., the duration of our threshold task), when the expression subsides, the predominating function served by disgust may lower thresholds.

We claimed that avoidant emotions improve olfactory detection, but for an avoidant emotion (e.g., disgust) to be triggered, one might argue that the trigger (e.g., foul smell) needs to be detected in the first place. Hence, on the surface, this appears to be the classic "chicken-and-egg problem": How would one happen without the other first happening? For our theory to be logically coherent, it is important to qualify that the trigger of an avoidant emotion and the outcome to be detected are two separate entities. It would be logically incoherent to claim that seeing images of thrash would improve visual detection of trash. However, it would be logically coherent to claim that seeing images of thrash would improve olfactory detection of thrash (see also Supplemental Materials S2).

Several alternative explanations might be considered. First, one might argue that our findings were because of mere negative valence induced by emotional states. However, this is unlikely because individuals in a depressive state (as an example of negative emotional condition) typically have higher olfactory thresholds (Pollatos et al., 2007; Schablitzky & Pause, 2014). Second, one might argue that our findings were because of response bias, in which participants simply tended to report smelling something when they did not. Such response biases may occur in paradigms in which, after the presentation of each odorant (or blank), participants are asked to indicate whether they detected an odor or not. However, because the present threshold procedure is a task in which participants indicate which of the sticks contained the target odorant (a triple-alternative forced-choice

paradigm), such response bias cannot exist (Macmillan & Creelman, 1991). The Sniffin' Sticks thus yields an unbiased measure of olfactory threshold. Third, one might argue that our findings were simply the effect of increased arousal when experiencing disgust or fear, rather than avoidant emotions per se. Without examining other emotions (e.g., nonavoidant negative emotions), our experiments cannot conclusively demonstrate that the lowered threshold was specific only to avoidant emotions and not highly arousing emotions per se. However, it is unlikely that our effects were simply because of arousal, because in Study 2.1, when we presented arousing tasty food stimuli (in the appetitive condition), olfactory threshold did not differ between this condition and the neutral condition, and threshold differed between the appetitive condition and disgust condition. Fourth, it is possible that participants sniffed harder (inhaled more volume of air) in some conditions, but this is unlikely to affect our results. Some participants indeed sniffed harder, but only for the first few sticks at the beginning of the experiment. Whenever that happened, our research assistants reminded participants to sniff normally. All participants complied. To reiterate, the first few sticks are not counted toward the threshold calculation. (Threshold was calculated from the last four reversals.) Nevertheless, without a spirometer, we cannot rule out the possibility that participants may have sniffed harder on some trials (sticks) without our assistants noticing.

One might wonder whether our effects were because of attention, because attention is known to increase sensitivity across sensory modalities (e.g., Carrasco, 2006). External attention refers to the selection and modulation of sensory information (Chun, Golomb, & Turk-Browne, 2011). Our procedure controls for external attention

(spatial, temporal, and object-based attention; Keller, 2011) because participants knew *where* to sniff, *when* to sniff, and *what type* of scent they were supposed to detect. Hence, it is unlikely that our results were because of external attention. Internal attention, on the other hand, refers to the selection, modulation, and maintenance of internally generated information, such as task rules, responses, long-term memory, or working memory. Internal attention includes cognitive control processes and operates over representations in working memory, long-term memory, task rules, decisions, and responses (Chun et al., 2011). In our paradigm, after every sniff, participants had to store neural representations of the current scent in working memory, compare this new memory representation with the one that was previously stored, decide whether the current scent was the same as the stored scent, inhibit competing representations, and so on. These processes involve cognitive control (Chun et al., 2011), which itself is increased under avoidant states (Koch, Holland, & van Knippenberg, 2008). Therefore, future research may wish to explicate the role internal attention and its components play.

The odor used in the present threshold measurement was *n*-butanol, which is commonly used for assessing olfactory thresholds. *N*-butanol is regarded as a "neutral" scent and smells like whiteboard marker ink (Hummel et al., 1997). It still has to be established whether our effects depend on the qualitative nature of particular scents. If the perceptual system is optimally tuned to different kinds of olfactory threats, then this ability may be enhanced by emotions most fitting with the kind of threat. For example, disgust may lower olfactory thresholds even more acutely for smells indicative of microbial threats (see Olsson

et al., 2014), whereas the same goes for fear and nonmicrobial threats (e.g., smoke). Future research may wish to investigate this.

Our olfactory system is already well-tuned to detect possible threats via smells (Doty, 2003; Herz, 2008). The so-called "absolute thresholds" for more than 500 odors have already been determined in past research (Devos, Patte, Rouault, Lafort, & van Gemert, 1990). This may have misleadingly suggested that olfactory thresholds are immutable—that thresholds represent the limit of human olfactory performance. However, the present research shows that what we interpreted as "absolute thresholds" may not be as absolute as we think. It appears that functionally relevant emotions such as disgust and fear enhance our smell capabilities to the extent that they allow us to detect odors at substantially lower concentrations than we normally are able to do.

Supplementary Material

S1: Computing a detection advantage across all experiments

Consider the two threshold values, y_{neutral} and y_{disgust}, that were measured in all three experiments. The ratio of this difference is:

$$\frac{y_{\text{neutral}}}{y_{\text{disgust}}} = \frac{0.04(2^{1-\text{dilution step of neutral}})}{0.04(2^{1-\text{dilution step of disgust}})}$$

This equation simplifies to:

$$\frac{y_{\text{neutral}}}{y_{\text{disgust}}} = 2^{(-\text{dilution step of neutral + dilution step of disgust})}$$

Or simply:

$$\frac{y_{\text{neutral}}}{y_{\text{disgust}}} = 2^{(\text{difference in dilution steps between disgust and neutral})}$$

S2: An example of the detection advantage in real life

Thresholds can also be meaningfully related to the physical world by computing a detection advantage, as shown above. The detection advantage across three experiments can then be further interpreted using real-life quantities, for example, in the time taken to detect the odor. We illustrate the potential implications by using the example of the detection of a gas leak. Suppose there is a gas leak from a pipe that releases 1 cubic unit of methanethiol per second. Assume that the threshold of detecting methanethiol is 20 cubic units in an affectively neutral state. With a 1.62 detection advantage during a

fearful state, 12.3 cubic units would be needed to detect methanethiol. See Figure 5 below. It will take 20 seconds to detect methanethiol in an affectively neutral state (T_N), and only 12.3 seconds in a fearful state (T_F). This extra 7.7 seconds can be life-saving. Care must be taken, however, not to interpret this detection advantage as pertaining to the mean difference of individual participants' concentration levels between the neutral and emotion condition. Instead, it pertains to a translation of the difference between the condition means of participants' thresholds in terms of mean dilution steps into the physical concentrations reflected by these means. However, as we mentioned in our article, the object that triggers disgust has the same identity from the target to be detected. That is, it is logically incoherent to say that gas leaks trigger fear, which in turn triggers detection of gas leaks. Hence, it is prudent to qualify that there must first be another trigger of fear (not the gas leak), in order for an individual to have an olfactory detection advantage towards the gas leak.

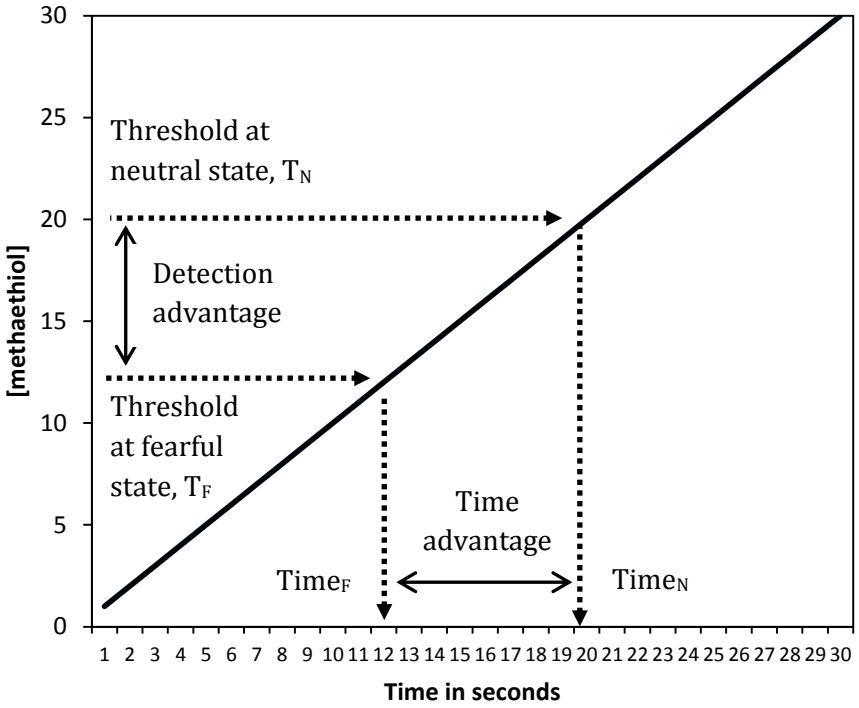


Figure 5. A hypothetical plot to illustrate how threshold detection advantage at fearful (F) or neutral (N) states can be translated to detection time advantage, assuming that the concentration of methanethiol increases at 1 cubic units per second.

CHAPTER 3

Disgust Lowers Olfactory Threshold, But Does Scent Valence Matter?*

Abstract

The olfactory system provides us with rich information about the world, but the odors around us are not always detectable. Previous research (Chan, Holland, van Loon, Aarts, & van Knippenberg, in-press) has shown that disgust enhances olfactory sensitivity to *n*-butanol, which incidentally is mildly negative. Thus it is unclear whether disgust, being a negative emotion, enhances sensitivity to stimuli with negative qualities, or across stimuli in general. Here we tested these competing hypotheses by examining thresholds to two scents, one positive (phenylethanol) and one negative (*n*-butanol), during a disgust, happiness, and neutral emotion induction. Our results indicated no valence-fit effect: Disgust, compared to the other two emotions, lowered olfactory thresholds to both *n*-butanol and phenylethanol equally. This suggests that disgust facilitates the detection of smells in general. Our results suggest that disgust facilitates the perceptual detection of extremely faint targets presumably because avoidant emotions enhance perceptual vigilance in general.

* This chapter is based on: Chan, K. Q., van Dooren, R., Holland, R. W., & van Knippenberg, A. (under review). *Disgust lowers olfactory threshold, but does scent valence matter?*

Emotions are not only functional at the behavioral level, but also at a perceptual level; they provide more information about the situation, such as whether the situation is benign or dangerous, so as to allow us to orchestrate our responses to environmental challenges adaptively (see Levenson, 1999). Indeed, in recent years, there has been some research demonstrating that emotions such as disgust and/or fear adaptively increases visual contrast sensitivity, and spatial and temporal resolution (e.g., Anderson, 2005; Bocanegra, & Zeelenberg, 2011a; 2011b; Phelps, Ling, & Carrasco, 2006; Sherman, Haidt, & Clore, 2012). These perceptual enhancements are presumably functional — a better visual contrast sensitivity would enable an organism to better discriminate what is clean versus contaminated; a better spatial resolution would enable an organism to see fine objects from a distance; a better temporal resolution would enable an organism to detect objects quicker.

Much of this research on the adaptive functions of emotions in perception have focused only on vision (e.g., Anderson, 2005; Bocanegra, & Zeelenberg, 2011a; 2011b; Phelps, et al., 2006; Sherman et al., 2012). Recently, researchers (Chan, Holland, van Loon, Aarts, & van Knippenberg, in-press) have also found perceptual enhancements in olfaction. In that research, participants saw disgust- or fear-inducing pictures while olfactory thresholds to *n*-butanol were obtained. During the threshold measurements, participants were presented with odorant sticks containing *n*-butanol of different concentrations simultaneously with neutral blank sticks (Hummel, Sekinger, Wolf, Pauli, & Kobal, 1997). The participants' task was to discriminate which stick contained the target scent. The reliable stick concentration when this discrimination was consistent was taken as the individual's olfactory

threshold. The researchers consistently found that disgust and fear both lowered olfactory thresholds to *n*-butanol, implying that when experiencing these emotional states, individuals *can* detect a scent that they normally would not be able to detect. Although the effect was repeatedly obtained across three studies, the underlying mechanism remains unclear.

There are two possible interpretations for the finding of Chan et al. (in-press). According to the authors (Chan et al., in-press), odors contain information about a particular object (e.g., food spoilage) or environment (e.g., smoke) but these odors are not always obvious. It is important to detect them because these odors may signal danger. However these odors may manifest in extremely low concentrations, making detection very difficult. Because disgust and fear are both avoidant emotions, the authors surmised that these emotions lowered olfactory thresholds due to vigilance evoked by avoidant emotions to faint odors in general. We call this the *general vigilance hypothesis*.

However, there is an alternative explanation for their findings. This other interpretation is based on Chan et al.'s (in-press) use of *n*-butanol in assessing olfactory thresholds. Although *n*-butanol is known in the literature to be a neutral odor, in our pretests, when asked to rate the valence of the smells, participants generally found it somewhat negative (see appendix for more information about these tests). Because both the independent variable (disgust and fear) and dependent variable (scent) were negative, individuals might have a lowered olfactory threshold because the valence of the emotion matched the valence of the scent. We call this the *valence-fit hypothesis*.

Some research has indicated that perceptual performance is improved when the valence of one's psychological state matches that of

the stimuli (Niedenthal & Setterlund 1994). For example, when negative or neutral words were flashed very quickly on screen (i.e., at threshold durations), sad participants compared to controls recognized more negative words than positive words (Powell & Hemsley, 1984; Small, 1985). However, other research has suggested that emotions can improve perceptual performance even when neutral stimuli were used. For example, fear lowered visual contrast sensitivity to gabor patches (Phelps et al., 2006), grey squares/numbers (Sherman et al., 2012), and improved spatial resolution to Landolt circles (Bocanegra, & Zeelenberg, 2011a; 2011b). These stimuli are all neutral. Therefore, both the general vigilance hypothesis and valence-fit hypothesis could hold. On the basis of Chan et al's (in-press) data and other findings (Bocanegra, & Zeelenberg, 2011a; 2011b; Phelps et al., 2006; Powell & Hemsley, 1984; Sherman et al., 2012; Small, 1985), it is unclear which account constitutes the most plausible explanation for Chan et al.'s (in-press) findings.

In the present research, we sought to tease apart which explanation was more likely. That is, how general is the disgust-threshold effect—does disgust improve general olfactory sensitivity or only to odors that have specific valence qualities? We addressed this question by using one positive scent, phenylethanol ("rose scent"), and one negative scent, *n*-butanol (same scent as used before by Chan et al. [in press]). We employed three emotion induction conditions: disgust, neutral, and happiness by exposing participants to emotion-inducing pictures. A happiness condition was included because it allowed a second, and stronger test of the valence-fit hypothesis. That is, if the valence-fit hypothesis holds, then *n*-butanol (negative) thresholds would be lowered only in the disgust condition and phenylethanol

(positive) threshold would be lowered only in the happiness condition. However, if the general vigilance hypothesis holds, olfactory thresholds would be lower in the disgust condition compared to the neutral and happiness conditions, irrespective of the odor's valence. Also, the general vigilance hypothesis would not predict any effect of the happiness induction on olfactory thresholds. Finally, because Chan et al. (in-press) found that *n*-butanol thresholds in the disgust condition decreased as disgust sensitivity increased, we also included a measure of disgust sensitivity (van Overveld, de Jong, Peters, & Schouten, 2011; see also Tybur, Lieberman, & Griskevicius, 2009).

Study 3.1

Method

Participants and Design

Sixty participants (48 females) were recruited from Radboud University. Their mean age was 21.4 (*SD* = 2.2). We used a 3 (Emotion: disgust [D], neutral [N], and happiness [H]) × 2 (Scent type: *n*-butanol, phenylethanol) fully within-participants design. Participants were randomly assigned to one of the six emotion counterbalanced orders (DNH, DHN, NDH, NHD, HDN, HND); within each emotion order, half of the participants would be tested with *n*-butanol first, and the other half with phenylethanol first.

Procedure

As in Chan et al. (in-press), the experiment was introduced as one testing the effect of smells on memory, and olfactory threshold was assessed intermittently within the emotion manipulation. Olfactory

thresholds were assessed using Sniffin' Sticks, an established test kit for research and clinical diagnosis (Hummel et al., 1997). This test consists of a series of 16 triplets of tubes. Each triplet includes one tube containing a target odorant (*n*-butanol or phenylethanol) in progressive dilution steps by a factor of 2, starting from a concentration of 0.04 (Stick #1) to 1.2×10^{-6} (Stick #16) *n*-butanol or phenylethanol. At the start of each block, participants were familiarized with the scent (Stick #2) that they would be detecting for that particular block. On each trial, two pictures were shown for 5 seconds each, followed by two rounds of olfactory threshold assessment. Each round involved participants smelling a triplet of odor sticks from the Sniffin' Sticks battery. During each round, the experimenter randomly presented three sticks in succession from the same triplet. Of the three sticks, one contained the target odorant (target stick) and the other two sticks were blanks. Participants' task was to indicate which stick smelled different from the other two.

If the response was incorrect, the next triplet containing a target stick of a higher odorant concentration (i.e., one step higher) would be presented. On subsequent triplets, the target stick's odorant concentration increased by one step at a time. Eventually a correct identification would occur. When that happened, the next triplet containing a target stick of lower concentration was presented (i.e., a reversal of the staircase). Subsequent correct responses would further lower the target stimulus concentration, while incorrect responses would increase the concentration (a new reversal). This procedure was repeated and ended only when seven reversal points were obtained. This constituted one experimental block. The threshold dependent variable was computed as the mean of the last four staircase reversal

points (Hummel et al., 1997), where 1 represents the lowest sensitivity (highest threshold) and 16 is the highest sensitivity (lowest threshold).

When a block ended, this was followed by two tasks: (i) a memory test, which helped bolster the cover story; and (ii) a filler task. In the memory test, a collage of 25 pictures was presented and participants had to indicate which pictures had not been presented earlier. For the filler task, we used the same one as Chan et al. (in-press) where participants had to identify, as quickly as possible, faint numbers (RGB = 255, 255, 255) that progressively darkened at -1 RGB/s. The data of this filler task was not analyzed.

At the end of the sixth block, participants completed a manipulation check procedure: they sniffed a blank stick, Stick #2 (high concentration) of phenylethanol and *n*-butanol, all separately and in a randomized order; they then completed valence ratings of these odors from (1) *Not at all pleasant* to (7) *Highly pleasant*. Finally, participants completed demographic measures and the Dutch version of the Disgust Sensitivity Questionnaire (van Overveld et al, 2011), which measures the tendency to experience disgust in daily life. Participants were finally thanked and debriefed.

Results

Manipulation checks for scent valence

Manipulation checks revealed that the valence rating for the neutral blank (M = 4.05, SD = 0.85) did not differ from the midpoint (i.e., 4.0) of the scale, $t(59) = .42$, $p = .67$. Compared to the neutral blank, phenylethanol smelled more positive (M = 4.72, SD = 1.77), $F(1, 59) = 12.7$, $p = .001$, $\eta_p^2 = .17$, whereas *n*-butanol smelled more negative (M = 3.38, SD = 1.56), $F(1, 59) = 7.49$, $p = .008$, $\eta_p^2 = .11$; hence the difference

in valence between phenylethanol and *n*-butanol was expectedly strong, $F(1, 59) = 15.9$, $p < .001$, $\eta_p^2 = .21$.

Because the scent valence manipulation check was conducted at the end of the sixth threshold block, we also included other independent variables (i.e., Scent order and Emotion order) in our analyses on valence. The main effects of Scent order, $F(1, 48) = 0.10$, $p = .75$, and Emotion order, $F(5, 48) = 0.60$, $p = .70$, on scent valence were also nonsignificant. For the higher order interactions, we found no significant Scent type × Scent order × Emotion order interaction, or Scent type × Emotion order interaction, Fs(10, 94) < 1.24, ps >.27, on scent valence. We did, however, find an unanticipated Scent type × Scent order interaction, $F(2, 47) = 10.51$, $p < .001$; when thresholds for *n*-butanol were assessed first, the mean valence ratings for *n*-butanol ($M = 2.67$, $SD = 1.42$) were lower as compared to the neutral blank ($M = 4.23$, $SD = 0.56$) and phenylethanol ($M = 5.33$, $SD = 1.18$), ts(29) > 5.63, $p < .001$. However, when thresholds for phenylethanol were assessed first, the mean valence ratings for *n*-butanol ($M = 4.10$, $SD = 1.81$), neutral blank ($M = 3.83$, $SD = 0.59$), and phenylethanol ($M = 4.10$, $SD = 1.68$) did not differ significantly, ts(29) < 0.87, ps > .39.

To establish that the valence of the scents were indeed different, an independent sample of 41 individuals rated the valence of *n*-butanol, phenylethanol, and the neutral blank in a counterbalanced order, without any emotion manipulation prior to rating the valence. This time, no Scent type × Scent order effects were found, $F(10, 66) = 1.51$, $p = .16$. However, we still found that the valence of *n*-butanol ($M = 2.46$, $SD = 1.09$) was significantly lower than the valence of the neutral scent ($M =$

3.36, *SD* = .99), $t(39) = 7.39$, $p < .001$, which was in turn lower than the valence of phenylethanol (*M* = 4.56, *SD* = 1.31), $t(39) = 2.81$, $p < .001$.

Main analyses

We first performed a 3 (Emotion: Disgust, neutral, and happiness) ×2 (Scent type: *n*-butanol vs. phenylethanol) × Disgust sensitivity (continuous factor: linear covariate) × 6 (Emotion order) × 2 (Scent order: *n*-butanol first vs. phenylethanol first) mixed analysis of covariance (ANCOVA) with Emotion and Scent type as within-participant factors and Disgust sensitivity as covariate. The sphericity assumption was not violated, Mauchly's $W = .92$, $\chi^2(2) = 3.61$, $p = .16$. Neither Emotion order nor Scent order produced any main or interacting effects, all Fs < 1.80, ps > .12, $\eta_p^2 < .12$. Hence, subsequent analyses were collapsed across Emotion orders and Scent orders.

A 3 (Emotion) × 2 (Scent type) × Disgust sensitivity (continuous factor: linear covariate) mixed ANCOVA with dilution steps as the dependent measure revealed a violation of the sphericity assumption, Mauchly's $W = .89$, $\chi^2(2) = 6.90$, $p = .03$. From Figure 1, it is evident the variances in thresholds were systematically larger in phenylethanol than in *n*-butanol. Hence we report Greenhouse-Geisser corrections for the degrees of freedom when comparing means between scents. There was no main effect of disgust sensitivity, $F(1, 58) = .61$, $p = .44$, $\eta_p^2 = .10$, no three-way interaction, $F(1.80, 104.13) = .35$, $p = .68$, $\eta_p^2 = .006$, and no two-way interactions with Scent type, $F(1.80, 104.13) = .41$, $p = .53$, $\eta_p^2 = .007$, or with Emotion, $F(1.90, 104.13) = 1.43$, $p = .24$, $\eta_p^2 = .02$.

The crucial test of the valence-fit hypothesis is the Emotion × Scent type interaction. This interaction was nonsignificant, $F(1.79,$

105.82) = .85, p = .42, η_p^2 = .01 (see Figure 1). Because the valence manipulation check did not uphold in all scent order conditions, the valence-fit hypothesis was tested within each scent order condition. In none of the scent order conditions was the Emotion × Scent type interaction significant, Fs(2, 28) < .34, ps > .67, η_p^2 < .03.

The critical test for the general vigilance hypothesis is the main effect of emotion, which was indeed significant, F(1.88, 105.82) = 24.9, p < .001, η_p^2 = .30. Follow-up analyses revealed that disgust lowered thresholds compared to the Neutral, F(1, 59) = 41.83, p < .001, η_p^2 = .42, and the Happiness condition, F(1, 59) = 23.4, p < .001, η_p^2 = .28; thresholds in the Neutral and Happiness conditions did not differ from each other, F(1, 59) = 3.09, p = .08, η_p^2 = .05. There was also a main effect of Scent type, F(1, 59) = 43.9, p < .001, η_p^2 = .42, but this is theoretically uninteresting because thresholds of any two odorants are unlikely to be the same (see Devos, Patte, Rouault, Lafort, & van Gemert, 1990). When we repeated the analyses for each scent order, our analyses revealed that the main effects were significant in both scent orders, Fs(2, 28) < 4.55, ps < .02, η_p^2 > .25, and the comparisons between emotion conditions were likewise the same: disgust lowered thresholds compared to the Neutral, Fs(1, 29) > 9.42, ps < .005, η_p^2 = .25, and the Happiness condition, Fs (1, 29) = 4.11, ps < .05, η_p^2 = .12; thresholds in the Neutral and Happiness conditions did not differ from each other, Fs(1, 29) = 1.41, ps > .20, η_p^2 < .05. Taken together, despite the unsuccessful manipulation check in one of the scent order conditions, the valence-fit hypothesis is rejected in both scent orders and the general vigilance hypothesis is confirmed in both these conditions.

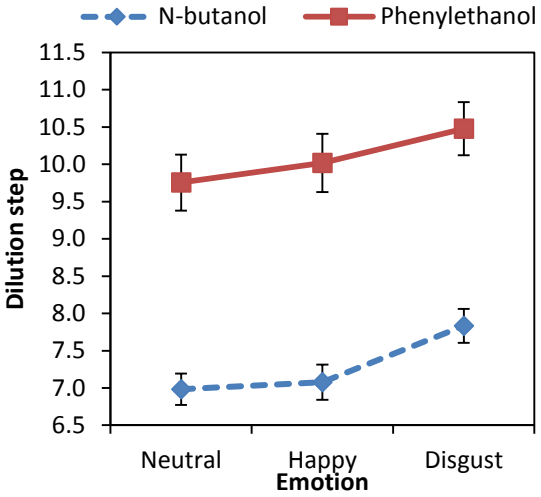


Figure 1. Plot of Emotion and Scent Type on thresholds. A higher dilution step means a lower threshold. Error bars depict standard errors.

Replicating previous results in Chan et al. (in-press)

In the above analyses, we replicated the main findings of Chan et al. (in-press): Within *n*- butanol, there was a strong effect of disgust compared to neutral pictures. However, in Chan et al. (in-press), there was also a significant interaction between Emotion and Disgust sensitivity. Specifically, their simple effects indicated that *n*-butanol thresholds decreased as disgust sensitivity increased in their Disgust condition, but not in their Neutral condition. We tested whether we could replicate these findings.

We ran a 3 (Emotion) × Disgust sensitivity (continuous) mixed-participants ANCOVA within the *n*-butanol conditions.[11] We found that disgust sensitivity did not produce any significant interactions, or main

[11] The same results were obtained even when the Happiness condition was excluded (i.e., a strict replication of Chan et al. [in-press]).

effects, *F*s(2, 116) = 1.40, *p*s > .25, η^2 = .02. Figure 2 displays the plot for the *n*-butanol scent in order to directly compare this study with that of Chan et al. (in-press). Although this Disgust sensitivity × Emotion interaction was nonsignificant, the pattern of results was similar to Chan et al. (in-press). Subsequent simple effects analyses revealed that, disgust sensitivity correlated significantly with *n*-butanol threshold in the disgust condition, *r* = .26, *p* = .04; correlations of disgust sensitivity with thresholds in the neutral and happy conditions were nonsignificant, -.01 < *r*s < .11, *p*s > .28. (Correlations of disgust sensitivity with phenylethanol thresholds in all three emotion conditions were also nonsignificant, -.02 < *r*s < .03, *p*s >.80.) In short, we did not replicate the Emotion interaction × Disgust sensitivity in Chan et al. (in-press), but we did replicate the simple effects of Disgust sensitivity within the Disgust condition.

Discussion

In summary, we found that disgust decreased thresholds to both *n*-butanol (a negative scent) and phenylethanol (a positive scent). We also found that happiness did not lower threshold to phenylethanol. These results suggest that disgust facilitates the perceptual detection of extremely faint olfactory targets not because the negativity of disgust is compatible with the negativity of the olfactory target (i.e., the valence-fit hypothesis), but because disgust triggers a general perceptual vigilance towards environmental olfactory cues (i.e., the general vigilance hypothesis). This conclusion is important because it clarifies the underlying mechanism behind how disgust enhances olfactory sensitivity.

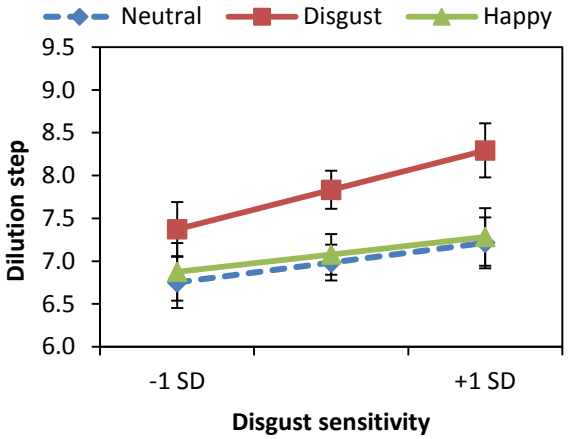


Figure 2. Effects of disgust sensitivity and emotion conditions on *n*-butanol thresholds. Higher dilution steps scores imply lower thresholds. The pattern of results is similar to Chan et al.'s (in-press) Studies 2 and 3. Note that Chan et al. (in-press), *n*-butanol, not phenylethanol, was used to measure thresholds. Error bars represent standard errors.

The rigor of our experimental design allowed us to confidently reject the valence-fit hypothesis in favor of the general vigilance hypothesis. In principle, comparing thresholds between *n*-butanol and a neutral valence scent vis-à-vis the disgust manipulation would have been sufficient. This is because neutral stimuli have traditionally been used to examine the effect of negative emotions (fear and disgust) on perceptual performance (Bocanegra, & Zeelenberg, 2011a; 2011b; Phelps, Ling, & Carrasco, 2006; Sherman, Haidt, & Clore, 2012). However, we compared thresholds of a positive and negative scent across positive, negative, and neutral emotions. Thus, this design constituted a stringent test of the valence-fit hypothesis, and the use of multiple scents also allowed us to test the general vigilance hypothesis simultaneously.

The manipulation check seemed not successful. This may be largely due to the limited diagnosticity of scent valence manipulation checks when manipulation checks are obtained after threshold measurements of about 10-15 minutes conclude. When individuals were asked to rate the valence of one or more target scents after one or several blocks of threshold measurements, it was unclear how carryover effects and prolonged sniffing changed individuals' evaluation of the scent. When we conducted the extra pilot test to ascertain the valence of *n*-butanol and phenylethanol, no order effects were found. This suggests that the original order effects in the scent valence evaluation could be spurious. In any case, the threshold effects were found within each scent order. Hence the order effect in scent valence ratings does not threaten our conclusions about the general vigilance hypothesis.

We did not fully replicate previous findings concerning the moderating role of disgust sensitivity on the relation between emotion and olfactory threshold. Although our pattern of results was similar, and simple correlations within the disgust conditions were obtained, the Emotion × Disgust sensitivity interaction of Chan et al. (in-press) was not significant. It is possible that there was not enough power to replicate the interaction.[12] Nevertheless, the main effect of emotions on

[12] We discovered that participants in our research sample (M = 3.23; SD = .58) had higher scores on disgust sensitivity than participants in Study 2 (M = 2.92; SD = .28) and Study 3 (M = 3.00; SD = .58) of Chan et al (in-press). A post-hoc contrast analysis with contrast weights of +2, -1, -1 respectively revealed that the mean disgust sensitivity of the current experiment is significantly higher than in their experiments, $F(2, 136) = 3.53$, $p = .03$. This suggests that in the current experiment, there might not have been enough participants who are at the lower end of the disgust sensitivity spectrum in order to replicate Chan et al's (in-press) Emotion × Disgust sensitivity interaction.

thresholds makes sense and is fully consistent with previous findings and reasoning (Chan et al., in-press).

One question remains: How general is the general vigilance hypothesis? There are two ways to examine this question: within modality and between modalities. Within the olfactory modality, "general vigilance" may imply that disgust should enhance olfactory sensitivity to all scents. In this research, we have tested two (*n*-butanol and phenylethanol) out of 1 trillion scents that humans can discriminate (Bushdid, Magnasco, Vosshall, & Keller, 2014) and our aim was not to show how general the effect of disgust on different scent thresholds is. We carefully chose two scents that differ in valence because this allowed us to examine which of two competing hypothesis was a better explanation for previous research (Chan et al., in-press). By ruling out the valence-fit hypothesis in favor of the general vigilance hypothesis, we have already advanced our understanding about the underlying mechanisms leading disgust to enhance olfactory sensitivity. However it remains an open question to what extent our findings generalize across all scents because there are more scents than we can reasonably test.

The question is more feasible to answer between modalities. Here, "general vigilance" may imply that disgust should enhance sensitivity across all perceptual modalities. Previous research revealed that disgust lowered threshold in visual perception (e.g., Sherman et al., 2012), and we extended this work to the olfactory threshold (see also Chan et al., [in-press]). It is interesting to test whether disgust might also lower thresholds in other domains across other sensory modalities. However, one must note that a functional perspective of emotions must work in tandem with a functional perspective of a particular perceptual

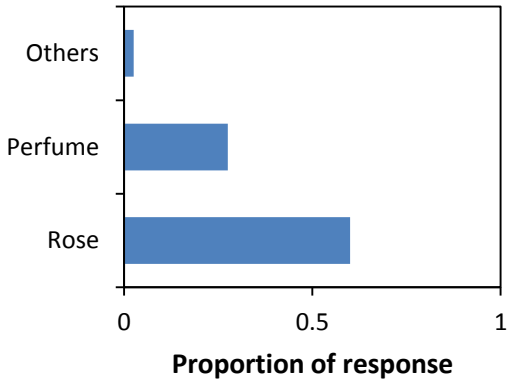
modality. Because a major function of disgust is to help the organism avoid pathogens (Oaten, Stevenson, & Case, 2009; Tybur, Lieberman, Kurzban, & DeScioli, 2013), it is useful for an organism in a disgust state to be able to detect subtle traces of pathogens. Pathogenic objects (e.g., rotten food) often have distinctive visual appearance (discolored), smell (rancid), taste (sour), and tactile feel (gooey), and that signal possible spoilage, but it is unlikely that pathogenic objects have distinctive sounds. Hence there may be strong evolutionary associations between disgust and vision, olfaction, gustation, and somatosensation, but not between disgust and audition. As such, disgust may also lower gustatory and haptic thresholds but not auditory thresholds.

To conclude, the current research bolsters the idea that avoidant emotions lower olfactory thresholds, for positive and negative smells. Further research is needed to determine how general is the effect of avoidant emotions on perceptual vigilance, both within and between modalities. However it may be too simplistic to assume that avoidant emotions such as disgust and fear lower thresholds to all sensory modalities without considering why it would be adaptive for that particular sensory modality to have a lowered threshold.

Appendix

Although *n*-butanol is typically regarded as a "neutral" odor (Hummel et al., 1997), its neutrality probably refers to its lack of consistent cognitive associations to any objects found in the environment. Humans are generally quite poor at describing odors (Majid & Burenhult, 2014). When asked to describe odors, people generally say that an odor "smells *like* [something else]". In a separate pretest, we asked 80 participants to sniff and then describe phenylethanol (free association; see Chan, Tong, Tan, & Koh, 2013, for similar methodology). Content analyses indicated that it smelled like roses or perfume, both of which fall under the modal category *flowers* (or floral scent); when we asked another sample of 39 participants to freely associate what *n*-butanol smells like, 22% indicated that it smelled like marker pens, 19% said it smelled like something "chemical". But unlike phenylethanol, there was no distinct dominant response (see Figure 3). Thus, *n*-butanol is neutral in the cognitive sense, but not in the evaluative sense, as suggested in the main text.

A: Phenylethanol



B: *n*-butanol

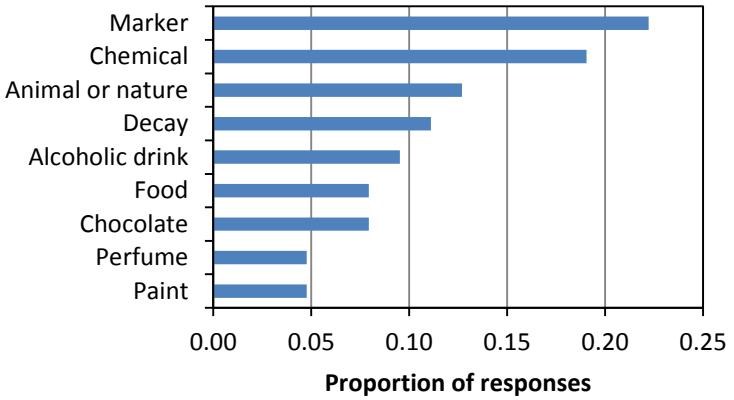


Figure 3. Qualitative responses when asked to describe phenylethanol (A) or *n*-butanol (B). It is evident that there are consistent cognitive associations of phenylethanol whereas this is absent in *n*-butanol.

CHAPTER 4

Vigilance in hearing: Avoidance motivation orientation lowers auditory thresholds[*]

Abstract

When individuals adopt an avoidant orientation (by any cause, e.g., explicit instructions, bodily feedback, threatening pictures), they become more vigilant, and enhanced vigilance arguably benefits from more acute processing of sensory information. In the current study we focus on the idea that avoidance-induced vigilance may enhance auditory performance in order to be better able to cope with potential threats. In Studies 4.1 and 4.2, we found that individuals performing an avoidance arm posture (vs. approach arm posture) had lower thresholds to high frequency (4000 Hz) tones than individuals performing an approach arm posture, but not to low frequency tones (1000 Hz). We postulated that this could be because high auditory frequencies tend to be judged more negatively, which we showed to be true using natural sounds (Study 4.3A) and pure tones (Study 4.3B). Novelty of high frequency tones could be an alternative explanation. However, by manipulating novelty of tones, Study 4.4 showed that the rarity of high frequency tones unlikely accounts for why avoidant

[*] This chapter is based on: Chan, K. Q., Holland, R., Hengstler, M., & van Knippenberg, A. (in-prep). *Vigilance in hearing: Avoidance motivation orientation lowers auditory thresholds.*

individuals had lower thresholds to high frequency tones. In contrast, by manipulating valence of 1000 Hz tones in Studies 4.5A and 4.5B, we showed that avoidant individuals have a lower threshold than approach individuals when tone valence is negative and not when positive, suggesting that tone valence is the mediator. A meta-analysis of our results suggests that the effect is relatively weak. Our research suggests that motivational orientation can engage consciousness at a very early stage in perceptual processing, even when signals are extremely weak.

Introduction

Human beings have well-tuned hearing capabilities suited to the ecology in which we live. A "normal" person has an auditory threshold close to 0 dB, can hear sounds between 20 Hz to 20,000 Hz (Martin & Clark, 2012), and has the ability to localize an object in space based at a minimum auditory angle of merely 1˚ (Mills, 1958; Perrott & Saberi, 1990). When assessing such auditory capabilities, researchers and clinicians typically discount or neglect the role of motivational states because what is typically of interest is the actual capabilities of the auditory system (e.g., threshold, discrimination, identification; Martin & Clark, 2012), or sensory characteristics of the stimuli (e.g., tone duration, timbre, frequency, etc.; see Hirsh & Watson, 1996). We suggest, however, that motivational states have an important influence on auditory sensitivity (see Zadra & Clore, 2011).

Approach and avoidance orientations are fundamental building blocks of human motivation (Elliot, 2008). An approach motivational orientation helps individuals to obtain essential outcomes including food, drinks, and partners. On the other hand, an avoidance motivational orientation prevents individuals from danger and negative outcomes. Thus, compared to approach motivational orientation, avoidance motivational orientation evokes vigilance, attention to detail, systematic information processing, and the recruitment of cognitive resources (see Koch, Holland, & van Knippenberg, 2008; Koch, Holland, Hengstler, & van Knippenberg, 2009; Roskes, Elliot, Nijstad, & de Dreu, 2013). This is adaptive because an avoidance state signals potential threats that may have to be dealt with. Extending the above studies, we examined the effects of motivational orientation at an even more basic level: perceptual thresholds in the auditory domain.

Perceptual thresholds represent a unique way to examine the adaptiveness of perceptual systems. An *absolute threshold*, in psychophysical terms, means the lowest amount of physical input that is needed to trigger a conscious experience of that input (Fechner, 1860/1966; see also Corso, 1963). While threats are often discernible by sight, some also manifest subtly. A predator preparing to pounce on its prey would increase its success if it moves as stealthily as possible; yet, a prey wishing to live another day would increase its success if it can detect such a predator as early as possible. Acting quickly after encountering threats is adaptive, but being able to detect a threat earlier rather than later is even more adaptive because pre-emptive actions can be performed. One potential way for an avoidance state to benefit perceptual systems is for it to allow the organism to be sensitive enough to detect signals, because some of these signals may signal threat. Hence we predicted that an avoidance state, being associated with vigilance, would lower auditory thresholds, making auditory cues possibly signally threat more easily detectable.

There has not been any direct evidence for the influence of motivational orientations on perceptual systems. However, there has been some research on how avoidant emotions tune perceptual systems. In emotion research, approach and avoidance concepts are central to many models of emotion (Elliot, Eder, & Harmon-Jones, 2013). For example, research has demonstrated that when individuals are exposed to fear-inducing stimuli (e.g., fear faces), they are better able to determine the left-right orientation of gabor patches (visual contrast sensitivity; Phelps, Ling, & Carrasco, 2006), detect whether a tiny gap exist in a C-shape stimulus (visual acuity; Bocanegra & Zeelenberg, 2009), or notice a negative target stimuli that is embedded among a

sequence of flashed distracters (inattentional blindness; Anderson, 2005). Recent research has also demonstrated that avoidance emotions such as disgust and fear lower olfactory (Chan, Holland, van Loon, Arts, & van Knippenberg, in-press), and visual thresholds (Sherman, Haidt, & Clore, 2012). These studies have focused only on vision and olfaction. Like any other sensory stimuli, sounds give us information about our immediate environment. However it is yet unknown if the effects found in vision and olfaction would generalize to audition. Furthermore, the involvement of both fear and disgust on these various perceptual tasks hints at the possibility that a more general avoidant motivational orientation may sharpen sensory capabilities.

Overview of the present studies

In Studies 4.1 and 4.2, we conditionally established the vigilance effect in hearing by testing the hearing thresholds to tones of various frequencies when participants were in an approach or avoidance motivational orientation state. To foreshadow some of our results, we obtained lower thresholds for high frequency, but not for low frequency sounds. We then posited two reasons for the moderating role of tone frequency: an avoidance orientation could trigger vigilance for (i) novel, or (ii) negatively valenced sounds. In Studies 4.3A and 4.3B, we first verified what tones were rare and negative. Then in Studies 4.4 and 4.5, we investigated whether rarity or valence of the tones could account for the vigilance effect in hearing. We disclose two failed attempts in the Appendix. No other studies were conducted in this line of research by our lab.

Study 4.1

In Study 4.1, we investigated whether individuals in an avoidance state have a lower auditory threshold. We first induced an approach or avoidance motivational orientation in our participants. There are several ways one can manipulate approach/avoidance orientation, such as (1) having participants complete an "unrelated" first task where they have to find a reward (e.g., a cheese) or avoid capture (Friedman & Förster, 2001); (2) presenting approach related pictures (e.g. tasty foods, vacation pictures) or avoidance related pictures (e.g. a bloody knife or disgusting food items); and (3) performing approach/avoidant body postures (e.g., Cacciopo, Priester, & Berntson, 1993). Our manipulation would need be "active" over the 5-10 mins duration of the threshold measurement (thus ruling out Option 1), and would not interfere with listening (thus ruling out Option 2). Hence we chose to induce approach/avoidant motivational orientation by having participants adopt arm flexion or extension postures while they performed the auditory threshold task (Option 3).

Arm extension is usually coupled with the onset of an unconditioned aversive stimulus, whereas arm flexion is usually coupled with the acquisition of desirable stimuli (Cacioppo et al., 1993; Chen & Bargh, 1997). Over time, these arm movements become associated with positive and negative outcomes, respectively. Via bodily feedback, enacting an avoidant arm extension posture may thus signal the presence of a problematic environment whereas enacting an approach arm flexion posture may signal the presence of a safe environment or the absence of threat. Having participants adopt an arm flexion or extension posture has been successfully used in many research as an effective means to trigger an approach or avoidance

motivational orientation, respectively (e.g., Cacioppo et al., 1993; Priester, Cacioppo, & Petty, 1996; Friedman & Förster, 2002; Slepian, Young, Rule, Weisbuch, & Ambady, 2012; Koch et al., 2008; Hengstler, Holland, Steenbergen & van Knippenberg, 2014), and its effectiveness is supported in a recent meta-analysis (Laham, Kashima, Dix, & Wheeler, 2014).

During the approach/avoidance manipulation, we assessed participants' auditory threshold toward two tones. Because tones between 250 Hz to 4000 Hz are recommended as stimuli for clinical assessment of hearing (American Speech-Language-Hearing Association, 2004), for exploratory reasons we used 250 Hz and 4000 Hz as test stimuli. We expected individuals in an avoidant motivational orientation to have lower auditory threshold to both tones than individuals in an approach motivational orientation.

Method

Participants and Design

Participants were 159 students (121 females) at Radboud University Nijmegen who participated for course credits or €5. Their average age was 22.12 (*SD* = 2.85). We used a 2 (Motivational orientation: approach vs. avoidance) × 2 (Tone frequency: 250 Hz vs. 4000 Hz) between-participants design.

Stimuli and Procedure

Participants were seated in a cubicle on chairs without armrests, with a computer monitor in front of them that presented all instructions. Half the participants were told to push a small foam ball up against the underside of their table (approach condition), whereas the

other half were told to push the ball down on the upper side of their table (avoidance condition; see Cacciopo et al., 1993; Koch, et al, 2008). Participants' auditory thresholds towards 250 Hz and 4000 Hz sine-wave tones, each with a tone duration of 100ms, and rise and fall times of 10 ms were assessed while they were in these approach or avoidance motivational orientation states.

To assess auditory thresholds, we used a *double interleaved staircase* design (Ehrenstein & Ehrenstein, 1999). Interleaved staircase designs are widely used to measure perceptual thresholds because they have many advantages over other methods such as the constant-stimulus method (Dai, 1995). In our design, there were two staircases: Staircase A and B. In each trial, participants heard a tone presented through their headphones. On trial 1 (Staircase A), participants heard a tone well above threshold intensity. On trial 2 (Staircase B), participants heard a tone well below threshold intensity. On trial 3, the next stimulus of Staircase A was presented (with a tone volume slightly lower than trial 1), and on trial 4, the next stimulus from Staircase B (with a tone volume slightly higher than trial 2), and so on. Participants' task was to left-click on the mouse whenever they hear a tone. For Staircase A, the stimuli intensity decreases by a certain number of decibels until it becomes too weak to be detected. At this point, the series was reversed (called a *reversal*) and the stimulus intensity was increased for the next trial. Conversely for Staircase B, the stimulus intensity increased until it was strong enough to be detected. When that happened, the series was reversed and the stimulus intensity was decreased for the next trial.[13]

[13] For the first two reversals, the tone volume was adjusted (increased or decreased, depending on whether it was the ascending trial or the descending

Over the course of the trials, the stimulus intensity flipped back and forth around the threshold value and eventually converged. In each staircase, there had to be seven reversals in order to arrive at the threshold intensity. The threshold was determined by the mean value of the last four reversals from each staircase (i.e., a total of eight reversals; see also Hummel et al., 1997).

Results

Two participants experienced computer problems and their data was not recorded. In addition, two outliers (> 3.5 *SD*s from the mean) were removed (the pattern of statistical significant and non-significant findings were identical when these participants were included). We performed a 2 (motivational orientation: approach vs. avoidance) × 2 (tone frequency: 250 Hz vs. 4000 Hz) between-participants ANOVA. Our analysis revealed that individuals have a lower threshold to 4000 Hz tones than 1000 Hz tones, $F(1, 150) = 6.84$, $p = .01$, $\eta_p^2 = .04$. This main effect of frequency is a standard finding in audiometry (see e.g. Robinson & Dadson, 1956). As we expected, avoidance individuals had a lower threshold than approach individuals, $F(1, 150) = 12.3$, $p < .001$, $\eta_p^2 = .08$. However, unexpectedly, these main effects were qualified by a significant interaction, $F(1, 150) = 17.9$, $p < .001$, $\eta_p^2 = .11$. Simple effects analyses showed that participants in the avoidance condition (compared to those in the approach condition) had lower thresholds for the 4000 Hz tone, $t(73) = 2.91$, $p = .005$, $d = 0.68$,

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trial, respective) by 6 dB; for the third reversal, the stimulus was adjusted by 3 dB. For the last four reversals, the stimuli were adjusted by 1 dB to arrive at a precise threshold measurement (see Cornsweet, 1962; Soranzo & Grassi, 2014).

but not for the 250 Hz tone, $t(81) = 0.35$, $p = .72$, $d = .08$. See Figure 1A. No other significant effects were obtained.

Discussion

We predicted that avoidant individuals would have a lower threshold across both tones, but instead found an effect only for the high frequency tone. We conducted Study 4.2 to further explore the nature of this interaction.

Study 4.2

In Study 4.2, we sought to replicate Study 4.1, and extended it by using 200 Hz, 500 Hz, and 1000 Hz tones, in addition to 4000 Hz tones used in Study 4.1. We chose the 200 Hz tone because this value captured the fundamental frequency of human speech (Puts, Gaulin, & Verdolini, 2006), which ranges from 80 Hz (males) to 240 Hz (females); we chose frequencies of 500 and 1000 Hz because these are standard frequencies used in audiometry (American Speech Language Hearing Association, 1978).

Method

Participants

We recruited 161 participants (133 females). Their mean age was 21.70 ($SD = 2.46$). The design was a 2 (motivational orientation: approach vs. avoidance) × 4 (tone frequency: 200 vs. 500 vs. 1000 vs. 4000 Hz) between-participants design.

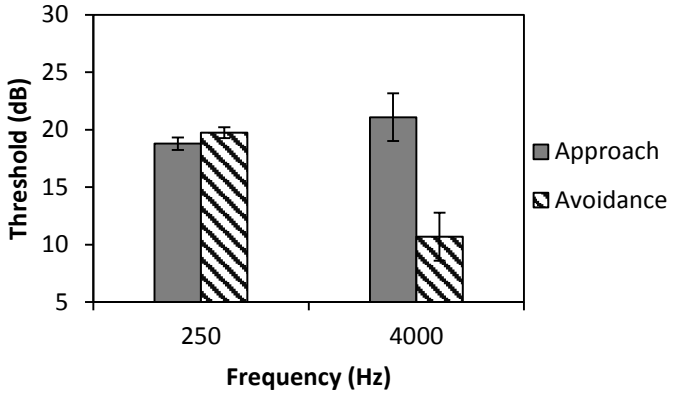
Materials and Procedure

We used 200 Hz, 500 Hz, and 1000 Hz tones, in addition to the 4000 Hz tones used previously. The procedure was otherwise identical to Study 4.1.

Results

No outliers were found in this study. A 2 (motivational orientation: approach vs avoidance) × 4 (tone frequency: 200 Hz, 500 Hz, 1000 Hz, 4000 Hz) ANOVA revealed no main effect of motivational orientation, $F(1, 153) = .90$, $p = .34$, $\eta^2 = .006$, however, a significant main effect of frequency, $F(3, 153) = 85.2$, $p < .001$, $\eta^2 = .63$, was found, just like in Study 4.1. More importantly, and in line with Study 4.1, we obtained a significant interaction, $F(1, 153) = 3.47$, $p = .01$, $\eta^2 = .06$. Simple effects analyses showed that avoidant participants compared to approach participants had a lower threshold only in the 4000 Hz conditions, $t(39) = 2.70$, $p = .01$, $d = .84$, but not in the other three conditions, $t(39) < 1.10$, $p > .28$, $d < .34$. Thus we replicated the effect of motivational orientation on auditory threshold for 4000 Hz. See Figure 1B.

A



B

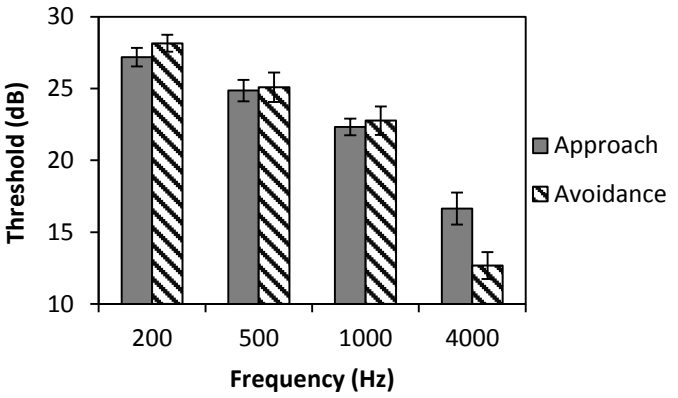


Figure 1. Plot of tone frequency and motivational orientation against auditory threshold in Studies 4.1 (A) and 4.2 (B). Error bars represent standard errors.

Discussion

Study 4.2 showed again that within the 4000 Hz condition, individuals with an avoidance (vs. approach) motivational orientation had a lower threshold. We posit two possible reasons why an avoidance

motivational orientation could favour the detection of high frequency sounds. First, high frequency sounds are rare in the environment. If an avoidance motivational orientation promotes vigilance, then it should promote vigilance to signals that are uncommon (see Clark, 2013). In line with this proposition, researchers have found that, fear and anxiety, both avoidant states, increased attention to novel stimuli (e.g., Bradley, 2009; Foote et al., 1983; Grillon, & Ameli, 1994; Svensson, 1987). In addition, other studies have shown that individuals who were high in state and trait anxiety (both related to avoidance orientation) had greater brain activity in response to novel stimuli (Hogan, Butterfield, Phillips, & Hadwin, 2007; Ousdal, Andreassen, Server, Jensen, 2014).

Second, we suspected that high frequency sounds are more unpleasant, and that people in an avoidance motivational state compared to an approach motivational state may be more sensitive to merely negative sounds. High frequency sounds such as sirens, a baby's cry, and screams, may signal possible threats in the environment (Goodman, 2009). Low frequency sounds, on the other hand, are often soothing and pleasing, such as meditation music, and in fact low frequency sounds have been proven to pacify irritable infants (Birns, Blank, Bridger, & Escalona, 1965). Past research has shown that perceptual performance was facilitated when the valence of the stimuli matched the affective nature of the motivational orientation (Niedenthal & Setterlund 1994). In one example, when participants had to pull or push to emotional words, they took less time to pull positive words towards them whereas they took less time to push negative words away from them (Chen & Bargh, 1999). If high frequencies are negative signals, then we should expect avoidance individuals to be more sensitive to high frequency sounds than approach individuals.

In Study 4.3, we first aimed to verify our assumptions about the rarity and valence of high frequency sounds. Then in Studies 4.4 and 4.5, by manipulating rarity and valence of sounds, we investigated whether rarity and valence could explain our findings in Studies 4.1 and 4.2.

Study 4.3

In Study 4.3A and 4.3B, we investigated whether high frequency tones were indeed rarer and also rated as more negative. In Study 4.3A, we analysed archival valence data in a sound database. In Study 4.3B, participants rated the valence of sounds of different frequencies.

Study 4.3A

A single source of a natural sound such as human speech spans a wide range of frequencies. For example, human speech can have a fundamental frequency of 80 Hz (males), and subsequent formants to 4000 Hz and above. However, what we most saliently experience as *pitch* is the fundamental frequency. In Study 4.3A, we extracted the fundamental frequency of emotionally evocative natural sounds from the International Affective Digitized Sounds (IADS; Bradley & Lang, 2007). These clips were three seconds long, and had previously been rated on pleasantness, arousal, and dominance (Bradley & Lang, 2007). We correlated pleasantness ratings with the extracted fundamental frequencies.

Method

Materials and Procedure

We extracted the fundamental frequency of each clip using Praat (Boersma & Weenink, 2014). Out of 167 clips, the fundamental

frequencies of 23 clips could not be identified by Praat and were thus excluded from the analysis. The names (stimuli number) of the excluded clips, as in the original Bradley & Lang (2007) dataset, were: *Crowd2* (311), *Office1* (320), *TypeWriter* (322), *Applause1* (351), *Baseball* (353), *Writing* (358), *CourtSport* (370), *Paint* (373), *Sink* (374), *Rain1* (377), *Jet* (400), *Helicopter1* (403), *Helicopter2* (705), *Phone2* (705), *Clock* (708), *Walking* (722), *Paper1* (728), *Paper2* (729), *WomanCrying* (280), *Shovel* (382), *Rain2* (698), and *Chewing* (724). One clip, *RattleSnake* (134), technically has no fundamental frequency because it contains sounds in constant power spectral density from 2000 Hz to 4000 Hz. In this instance, we conservatively coded *RattleSnake* as 2000 Hz. We then correlated these frequencies with the published pleasantness rating, which had been previously rated on 1 (*low pleasure*) to 9 (*high pleasure*) using a self-assessment manikin in Bradley and Lang (2007).

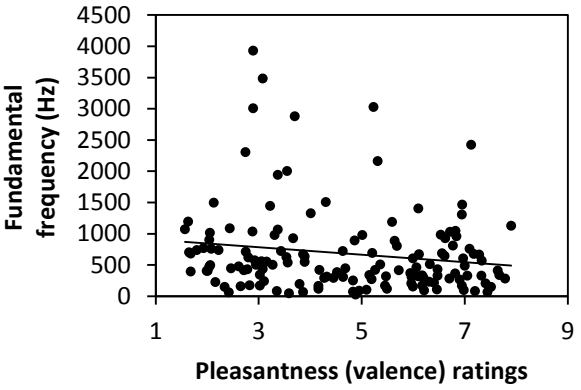
Results

High frequency sounds were indeed rated as more negative, $r(143) = -.16$, $p = .05$. Although homoscedasticity was not violated, Breusch-Pagan, $\chi^2(1) = .26$, $p = .72$, the frequency variable was highly skewed, $t = 11.97$, $p < .01$ (see Figure 2A). Hence we also repeated the correlation test using a log-transformed fundamental frequency (Breusch-Pagan $\chi^2(1) = .25$, $p = .61$; skewness $t = 1.63$, $p = .11$) and obtained identical results, $r(143) = -.16$, $p = .05$. Furthermore, from analyzing Figure 2A it becomes evident that high pitch sounds are rare in our natural environment. The fundamental frequencies of these natural sounds are typically less than 2000 Hz (median = 475 Hz).

Discussion

Consistent with our intuitions, individuals found high frequency sounds to be more negative. This is consistent with previous research which used another set of natural sounds (Kumar, von Kriegstein, Friston, & Griffiths, 2012). In addition, from the sample of sound clips we used, we also found that high frequency sounds are rarer in the natural environment. Although this sample of natural sounds is limited and may not be representative of our natural auditory ecology, it is probably acceptable to assume that we rarely hear pitches above 2000 Hz. The human voice can cover frequencies between 82 Hz and 1174 Hz, with the normal speaking of adult men averaging around 125 Hz and women averaging around 200 Hz (Titze, 1994); road traffic in cities is loudest at frequencies between 700 Hz and 1300 Hz (Sandberg, 2003); sirens typically range from 1000 to 3000 Hz; a 4000 Hz tone is approximately pitch of the highest C8 piano note (4186 Hz). Hence sounds at pitches around 4000 Hz are not common in everyday lives than the lower frequency sounds.

A



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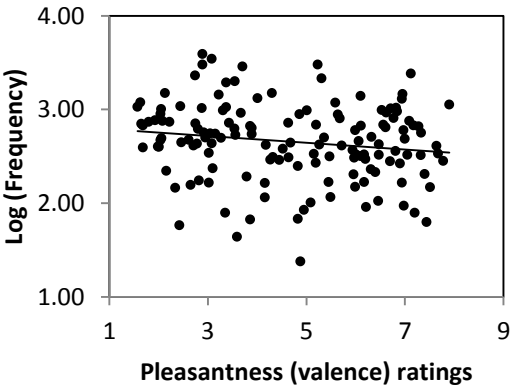


Figure 2. Plot of pleasantness ratings against frequency of tones (Hz) for raw (A) and log-transformed data (B). Each datapoint represents one sound clip. The trend lines represents the correlations between ratings and frequency.

Study 4.3B

Natural sounds allow us to test our intuitions in an ecologically valid way, but they are not content-free. Indeed some sound clips used

in Study 4.3A (e.g., screams) naturally have negative connotations, and they happened to be high frequency sounds. In Study 4.3B, we used content-free pure tones, which had two advantages: (a) It would allow us to test the pure effect of tone frequency on valence; (b) It would make our conclusions more relevant to Studies 4.1 and 4.2 where pure tone thresholds were assessed.

Method

Participants & Design

Thirty-two participants (23 females) took part; their mean age was 23.00 (*SD* = 3.08). Tones of different frequencies were presented to each participant in a within-participants design.

Materials and Procedure

Tones of 100, 250, 500, 1000, 2000, 4000, 12000 Hz were used. All tones were 100ms long, had 10 ms rise and fall times, and were 70 phons loud (Robinson & Dadson, 1956).

On each trial, participants heard a randomly selected tone presented thrice, with each instance separated by 1000 ms. After each tone, participants were asked the three questions assessing positive valence (α = .83) ("How positive / pleasant / soothing do you find the tone?"), and three questions assessing negative valence (α = .56)[14] ("How negative/unpleasant/irritating did you find the tones?"). They rated their evaluations from 1 = *Not at all* to 5 = *Very much*.

[14] The low reliability likely underestimates the relationship between negativity and frequency, but does not invalidate it (see Schmitt, 1996)

Results

Compared to low-frequency tones, high frequency tones were less positively evaluated, linear $F(1, 31) = 10.6$, $p = .003$, $\eta^2 = .26$, and simultaneously more negatively evaluated, linear $F(1, 31) = 5.18$, $p = .03$, $\eta^2 = .14$. From Figure 3, there were evident quadratic trends within each valence evaluation. Compared to mid-frequency tones, low and high frequencies were less positively evaluated, quadratic effect, $F(1, 31) = 20.9$, $p < .001$, $\eta^2 = .40$, and simultaneously more negatively evaluated, quadratic effect, $F(1, 31) = 10.6$, $p = .003$, $\eta^2 = .26$.

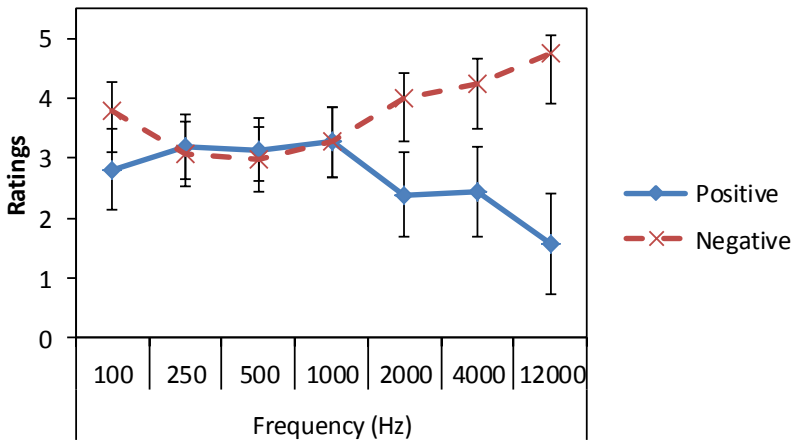


Figure 3. Plot of tone frequency against positive and negative ratings. Error bars represent 95% confidence intervals.

Discussion

Using content-free pure tones, Study 4.3B also found that high frequency tones were negatively evaluated. Taken together, Studies 4.3A and 4.3B verified our intuitions that high frequency sounds are both rare and evaluated negatively. In the coming studies, we sought to investigate whether rarity (Study 4.4) and/or valence (Study 4.5) can

explain why avoidance orientation lowers auditory thresholds only for high frequency sounds.

Study 4.4

Study 4.4 explored the rarity (or *novelty*) explanation. Past research has shown that the processing of novel stimuli is prioritized over familiar stimuli. For example, novel stimuli elicit more brain activation and the brain responds faster to novel auditory stimuli than to non-novel stimuli (Kiehl, Laurens, Duty, Forster & Liddle, 2001; Ranganath & Rainer, 2003). This is adaptive because novel stimuli signal changes in the environment that may be worth attending to. In addition, fear increased attention to novel stimuli (Foote et al., 1983; Svensson, 1987). Hence, it is possible that under an avoidant orientation, individuals' perceptual systems become more sensitive to detect stimuli that are novel—in this case, high frequency tones.

To test the novelty explanation, we manipulated the novelty of the tones—half the participants were habituated to the testing tone, while the other half were habituated to a non-testing tone. Thereafter their thresholds were assessed while they adopted an approach or avoidance posture, as in Studies 4.1 and 4.2.

Method

Participants

We recruited 119 participants (82 females) who participated for course credits or €7.50. Their mean age was 22.59 (*SD* = 3.20). The design was a 2 (Motivational orientation: Approach vs. Avoidance) × 2 (Habituation: Novel vs. Habituated) between-participants design.

Materials and Procedure

To manipulate novelty, participants did a "spatial localization task". In this task, there were 150 trials where a white circle was presented in a random location and participants had to click on it. At that instance, either a 4000 Hz or 500 Hz tone was presented. In the Habituated condition, participants heard only the 4000 Hz tones; in the Novel condition, participants heard only the 500 Hz tones. Participants then performed the auditory threshold task in an approach or avoidance arm posture for 4000 Hz tones, employing the same procedure as in Studies 4.1 and 4.2.

Results

No outliers were found in this study. A 2 (Motivational orientation: Approach vs Avoidance) × 2 (Habituation: Novel vs. Habituated) between-participants ANOVA revealed no interaction, $F(1,115) = 2.83$, $p = .10$, $\eta^2 = .02$, and no main effects of Motivational orientation, $F(1,115) = .37$, $p = .54$, $\eta^2 = .003$, or Habituation, $F(1,115) = .74$, $p = .39$, $\eta^2 = .006$. This indicated that the novelty of a 4000 Hz tone is unlikely to explain the approach/avoidance effects in Studies 4.1 and 4.2. In addition, planned contrasts revealed that within the novel 4000 Hz tone condition, there was no significant threshold difference between the approach ($M = 5.51$; $SD = 5.38$) and avoidance ($M = 8.31$; $SD = 6.85$) conditions, $t(58) = 1.62$, $p = .11$.

Discussion

The absence of an interaction between motivational orientation and habituation suggests that it is unlikely that the novelty towards 4000 Hz tone could explain the approach/avoidance effects in Studies 4.1 and 4.2. However, we also did not find that avoidance individuals (compared to approach individuals) had lower threshold towards 4000 Hz tones in the non-habituation control condition (i.e., in the conditions that most closely resemble Studies 4.1 and 4.2). If anything, the trend was in the opposite direction. Therefore, this study did not reveal conclusive evidence for the role of novelty in our thresholds effects of motivational orientation. We decided to continue to study our second possible interpretation: the role of valence.

Study 4.5

The purpose of Study 4.5 was to examine whether the negative valence of the 4000 Hz tone can explain why avoidant individuals have lower auditory thresholds only for higher frequency tones in Studies 4.1 and 4.2. Although we have established that 4000 Hz tones are negative in valence (Studies 4.3A and 4.3B), it is unclear whether negativity per se is the reason for the lowered thresholds among avoidance individuals. A direct manipulation of negativity would provide stronger evidence. In Studies 4.5A and 4.5B, we manipulated the valence of a tone via a conditioning procedure. We used a 1000 Hz tone in the conditioning procedure for two reasons: First, because the valence of the 1000 Hz tone was neutral (see results of Study 4.3B), we reasoned that it would be easier for it to acquire either a positive or negative valence; second, we postulated that it would be very difficult to

condition a 4000 Hz to become positive (or even less negative) because the valence of 4000 Hz tones is already extremely negative (Study 4.3B).

After the conditioning procedure, auditory threshold to the conditioned tones were assessed while participants were in an approach or avoidance state, employing the same arm movement manipulation as in our previous studies. We reasoned that if avoidance individuals had a lower threshold to high frequency sounds because the latter sounds are more negative compared to low frequency sounds, then avoidant individuals should have a lower threshold to negative valence tones than positive valence tones.

Study 4.5A

Method

Participants

We recruited 138 students (109 females) who participated in exchange for course credits or €5. Their mean age was 23.52 (*SD* = 6.80).

Procedure

As a pre-measure, we first assessed participants' evaluation towards 500, 1000, 4000 Hz tones (all calibrated to 70 phons) by asking them how positive (*beautiful*, *positive*, and *nice*; α = .86) and how negative (*negative*, *irritating*, and *threatening*; α = .80) they find the tones, on a scale of 1 = *Not at all* to 7 = *Very much*. Then, to manipulate valence, we paired the 1000 Hz tone with valenced pictures from the International Affective

Picture System (IAPS; Lang, Bradley, Cuthbert, 1997).[15] The negative pictures were selected to induce fear (e.g., threatening animals, gunpoint, etc.) and the positive pictures (e.g., appetizing food, romantic couples, etc.) were selected to match the negative pictures on arousal. A trial started with a fixation cross. After 500 ms, the tone was presented. In the Positive conditioning group, 200 ms after the tone a positive picture appeared for 950 seconds. After a delay of 1450 ms a negative picture appeared for 1650 ms. The procedure was reversed in the Negative conditioning group, such that the tone was immediately followed by a negative picture for 950 ms and, after a delay, a positive picture appeared for 1650 ms (see Figure 5). This setup ensured that each experimental condition was equally exposed to both positive and negative pictures, and that the only difference between groups was what the tone was paired with. There were 30 trials in total.

As manipulation check, when the conditioning phase ended participants again had to evaluate the same set of tones again employing the same scales. Finally, the auditory thresholds of the conditioned 1000 Hz tones were assessed while they were either in an approach or avoidance motivational state, as in Studies 4.1 and 4.2.

[15] The positive pictures were: 1999, 2000, 2040, 2050, 4599, 4601, 4603, 7200, 7351, 7352, 7360, 7380, 7390, 7430, 8380. The negative pictures were: 1120, 1300, 2690, 2691, 2800, 2900, 3015, 3220, 6190, 6250, 6300, 6510, 6940, 9253, and 9410.

Figure 5. The illustration depicts the negative conditioning procedure. For the positive conditioning procedure, the positive picture would appear first (at 950 ms), followed by the negative picture (at 1650 ms). *Note*: The actual images used were from the IAPS, which is copyrighted and hence not reproduced here.

Results

No outliers were found in this study. We first assessed whether our manipulation of tone valence was successful by comparing pre- and post-ratings using paired samples t-tests. Comparing pre- and post-ratings, when paired with negative stimuli, the 1000 Hz tone was rated as more negative, $t(67) = 2.22$, $p = .03$, and less positive, $t(67) = 2.18$, $p = .03$. Likewise comparing pre- and post-ratings, when paired with positive stimuli, the 1000 Hz tone was not less negative, $t(69) = 1.32$, $p = .19$, or more positive, $t(69) = 1.62$, $p = .10$. There were no changes in valence for the unconditioned 250 Hz and 4000 Hz tones ($ps > .11$). Hence the conditioning procedure was successful in changing the tone valence from neutral to negative, but not from neutral to positive.

A 2 (motivational orientation: approach vs. avoidance) × 2 (tone valence: positive vs. negative) revealed no significant interaction, $F(1, 137) = .002$, $p = .96$, $\eta_p^2 < .001$. There was no main effect of Motivational orientation, $F(1, 137) = .94$, $p = .34$, $\eta_p^2 = .007$. However, there was a

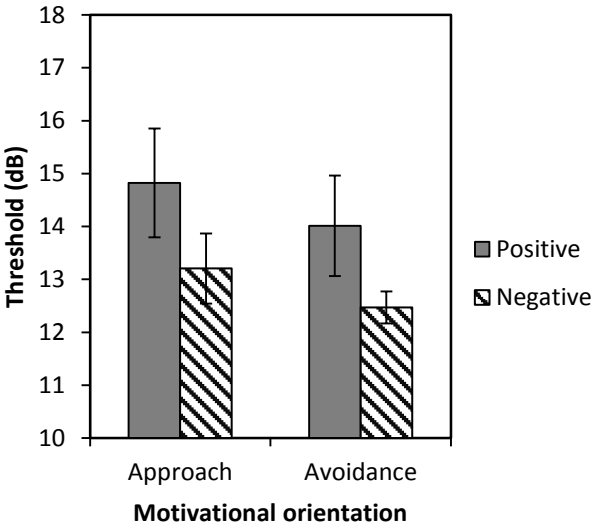
significant main effect of Tone valence, $F(1, 137) = 3.92$, $p = .05$, $\eta_p^2 = .03$, which showed that participants had a lower threshold to negatively conditioned 1000Hz tones. None of the four simple effects were significant (ts < 1.42, ps > .16). See Figure 6.

Discussion

Although there was no interaction between motivational orientation and valence of tone, this could be because the manipulation of tone valence was relatively weak. At the same time, the overall pattern of means was consistent with our predictions. Hence, for the next study, we improved on our design.

In addition, it is worth noting that participants had a lower threshold to negatively conditioned tones in general. Previously Stefanucci and Siegal (2007) found that participants who saw fear-inducing pictures rated supraliminal sounds as louder. Our findings thus complement theirs, although we acknowledge that loudness (the psychological judgment of a sound's intensity) and thresholds (the minimum intensity of a sound that is needed to trigger a conscious experience of the sound) are different concepts.

A



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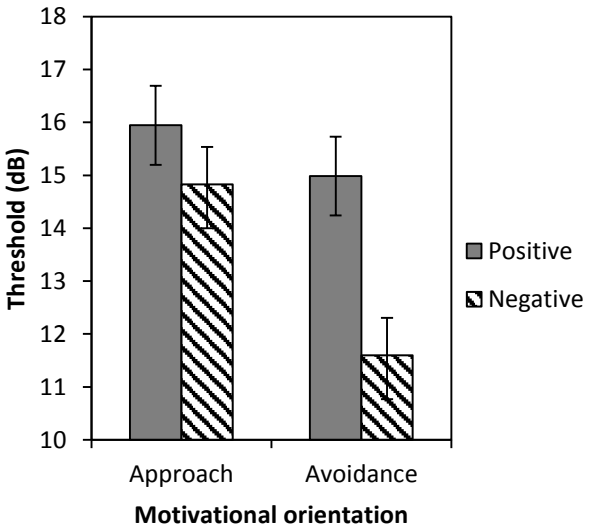

Figure 6. Plot of threshold against motivational orientation and tone valence for Study 4.5A (A) and 4.5B (B). Error bars represent standard errors.

Study 4.5B

Even though the conditioning procedure was strong enough to evoke an interesting main effect of valence on auditory threshold, the interaction with motivational orientation failed to reach significance. Perhaps, the latter interaction is only obtained when the sounds is strongly linked with a negative valence. Therefore, in Study 4.5B, we extended the conditioning procedure from by increasing the number of conditioning trials from 30 to 86.

Participants

We recruited 120 students (96 females) who participated in exchange for course credits or €5. Their mean age was 22.7 (*SD* = 4.9).

Materials and Procedure

All materials and procedure were identical to Study 4.4, except that in this study, the conditioning trials were extended to 86 trials.

Results

No outliers were found in this study. The manipulation checks indicated that the manipulation of valence was successful: The 1000-Hz tones paired with positive pictures were rated more positively, $t(122) = 2.82$, $p = .006$, whereas 1000-Hz tones paired with negative pictures were rated more negatively, $t(122) = 4.01$, $p < .001$. There were no changes in valence for the unconditioned 250 Hz and 4000 Hz tones ($ps > .27$).

A 2 (Motivational orientation: Approach vs Avoidance) × 2 (Tone valence: Positive vs. Negative) with threshold as the dependent variable revealed a main effect of valence, $F(1, 121) = 10.5$, $p = .002$, $\eta^2 = .07$, and a main effect of motivational orientation, $F(1, 121) = 7.47$, $p = .007$, $\eta^2 = .06$. However, there was no significant interaction, $F(1, 121) = 2.44$, $p = .11$, $\eta^2 = .02$. Despite the nonsignificant interaction, it was justified to conduct planned contrasts because we made prior predictions about the pattern of results (see Study 4.5A). Our contrast revealed that when a tone was conditioned to be negative, participants in the avoidance condition have a lower threshold, $F(1, 118) = 9.38$, $p = .003$, compared to participants in the approach condition. However, when a tone was conditioned to be positive, threshold differences between avoidance and approach individuals disappeared, $F(1, 118) = 0.71$, $p = .35$. Within the approach condition, tone valence did not produce a difference in threshold, $F(1, 118) = 1.15$, $p = .29$. However, within the avoidant condition, the negatively conditioned tones produced a lower threshold than the positively conditioned tones, $F(1, 118) = 10.54$, $p = .002$. See Figure 6.

Discussion

Our conditioning procedure appeared to successfully change the valence of the conditioned tones. In contrast to Study 4.5B, the evaluative ratings of the 1000Hz clearly changed in line with the unconditioned stimuli, both for the negative valence ratings and the positive valence ratings. More importantly, concerning our threshold results, the pattern of results thus suggests that when a signal is a safety cue, avoidant individuals no longer have an auditory detection

advantage for that particular signal. Hence, avoidant individuals have an auditory detection advantage for potentially threatening cues.

Meta-analysis

The studies thus far seemed to provide promising evidence for the influence for approach and avoidance orientations on auditory threshold. At the same time, the results were not consistently strong (e.g. Study 4.5A) and not always pointing in the same direction (e.g. Study 4.4 and Replication Study A). To find out how large this effect of avoidant motivational orientation on auditory threshold is, we performed a meta-analysis of all relevant studies on the threshold differences between approach and avoidance conditions. We selected only conditions that were relevant to our question and omitted conditions that were irrelevant (e.g., 250 Hz tones in Study 4.1, habituated 4000 Hz tones in Study 4.4, etc.). See Table 1 for a summary of relevant effect sizes.

Because we had all primary data, we performed an individual participant data (IPD) meta-analysis (Cooper & Pattall, 2009). Our analysis revealed that avoidant individuals had a significantly lower auditory threshold, $t(354) = 1.86$, $p = .05$, $d = .20$. Because participants were nested within studies, we conducted multilevel modelling using restricted maximum likelihood estimation method (Snijders & Bosker, 1999). In a random intercepts model, avoidant individuals had a lower auditory threshold, $b = 2.27$, $SE = .80$, $t = 2.86$, $p = .005$, 95% CI = [.71, 3.84]. When the effect was allowed to vary between studies (i.e., random slopes model), there were no significant differences in threshold between the approach and avoidant individuals, $b = 2.06$, $SE = 2.17$, $t = .95$, $p = .38$, 95% CI = [-3.45, 7.58]. Performing a conventional

aggregate data meta-analysis (Lipsey & Wilson, 2000) yielded similar conclusions: fixed effect d = .31 [.10, .52], p = .004, random effect d = .31 [-.19, .80], p = .23.

It is prudent to note the inconsistent confidence levels between the models, as well as the small sample of studies. The fixed effect model is appropriate for interpreting the robustness of the results in our collection of studies (Hedges & Vevea, 1998), and by that, it means that avoidant motivational orientation lowers auditory threshold within our studies. However, random effect models would be preferred when making inferences about future attempts (Hedges & Vevea, 1998).

Table 1.

Summary of Relevant Effect Sizes for the Meta-Analysis

	Condition		Sample size		
Study	1	2	n_1	n_2	d
4.1	App-4000 Hz	Av-4000 Hz	39	36	.68
4.2	App-4000 Hz	Av-4000 Hz	21	20	.84
4.4	App-Novel	Av-Novel	31	29	-.45
4.5A	App-Negative	Av-Negative	37	32	.24
4.5B	App-Negative	Av-Negative	31	28	.77
Rep A	App-4000 Hz	Av-4000 Hz	27	27	-.42

Note: A positive d means that avoidance individuals have a lower threshold. App: Approach; Av: Avoidance; Rep A: Replication A.

General Discussion

Our original hypothesis was that an avoidance motivational orientation would lower auditory thresholds in general. However, in both Studies 4.1 and 4.2, we found this to be true only for high

frequency sounds. Because high frequency sounds are rare and negatively valenced (Studies 4.3A and 4.3B), we further investigated whether rarity or valence of tone could result in avoidant individuals having lower threshold. We found no impact of motivational orientation on threshold when tone novelty was manipulated in Study 4.4. However, in Studies 4.5A, the pattern of results, though nonsignificant, suggested that avoidance individuals had a lower threshold when a neutral tone acquired a negative valence. With a stronger conditioning paradigm in Study 4.5B, this pattern was statistically significant. For approach individuals, tone valence did not affect their thresholds. Conceptually, these results suggest that an avoidance state improves one's auditory detection capabilities for negative stimuli. The current literature has shown that fear and disgust lower visual and olfactory thresholds (Chan et al., in-press; Phelps et al. 2006; Sherman et al., 2012). Because fear and disgust are both avoidant emotions, our research has not only extended from visual and olfactory thresholds to auditory thresholds, but also suggests that an avoidance motivational orientation may be a more general mechanism that sharpens our senses.

Several limitations should be mentioned. One, some of our studies may be underpowered. We calculated our sample size based on the first study we conducted (Study 4.1) where we obtained a large effect size with a large sample size. But subsequent studies had smaller effect sizes, such that the overall the effect size is small. One reason could be that the particular avoidance manipulation we used (arm extension) produces a weak avoidance motivational orientation. Another reason could be that the nonspecific nature of an avoidance motivational orientation expectedly produced a smaller effect size. It is possible that stronger effects could be obtained if other ways of

manipulating avoidance were used (e.g., prevention-focused instructions) or specific avoidant emotions (e.g., fear or disgust) were primed. Nevertheless, our results are fully consistent with the effects of avoidant emotions, such as fear and disgust in other domains of perceptual threshold (Chan et al., in-press; Phelps et al. 2006; Sherman et al., 2012). Two, we attempted to rule out the novelty explanation by manipulating tone novelty in Study 4.4 but the evidence was inconclusive. In retrospect, it is difficult to test the novelty explanation because of the way thresholds are measured. All reliable threshold measurements (staircase paradigms, sequential testing, maximum likelihood procedures; Soranzo & Grassi, 2014) require multiple exposures to the auditory stimuli during an experimental setting. Hence the measurement of auditory threshold itself already makes the stimuli not novel anymore.

Readers should note that by international convention, the threshold for 1000 Hz tones is fixed at 0 dB, and the thresholds of 250 Hz to 4000 Hz tones ranges from 15 dB to -5 dB (Robinson & Dadson, 1956). Our obtained threshold values are far from these values probably because the international readings were obtained in a closed field (using insert earphones, sound-attenuated chambers), whereas ours were obtained using normal earphones in a non-sound-attenuated chamber. Our threshold values also varied from study to study, because of the difference in ambient room noise. Therefore, one should not take the threshold values of any particular study as the standard for comparison with other studies, either our own or others'; the important contrast is the *relative difference* between experimental groups within each study.

Sounds convey unique ecological signals that other signals cannot convey. For example, because light travels in a straight line but sound bends around corners, one can hear threats coming even if the threat is out of sight. More pertinent to our research, mean threshold differences can be meaningful understood as distance advantage. Although the mean threshold difference of 2.19 dB seem small (see Meta-analysis), at threshold level, this equates to a 0.22 detection advantage in distance for avoidance individuals' (see Online Supplementary Materials for the derivation). In other words, avoidance individuals would be able to detect the sound made by one hissing snake at threshold level 10 m away, whereas approach individuals would detect the snake only when it is as near as 7.8 m. The additional 2.2 meters could be life-saving.

That humans interpret things in ways that are consistent with their motives (Balcetis & Lassiter, 2011) is not new as ample research has demonstrated that motivation affects various aspects of social cognition. At a lower level, some research has shown that motivation modulates attentional processes (Todd & Anderson, 2011). But before anything gets attended to, they must first be detected. Although stimuli characteristics undoubtedly play a major role in detection (Hirsh & Watson, 1996), this research showed that motivational orientation can influence even the very basic level of our sensory experience.

Appendix

Here we disclose two failed replications. These were performed sequentially after Study 4.2. We computed our sample size (80% power) based on the effect size of Study 4.1. We ran Replication A (N = 54) in a sound-isolated chamber (ambient noise level = 29 dB) used primarily for music cognition experiments. In addition to standard lab computers, this chamber also had a drum set, grand piano, sofa, and ambient lighting – all of which we could not remove. Participants performed the approach or avoidance manipulations while their thresholds to 4000 Hz tones were measured. Avoidance individuals had higher thresholds (M = 16.05; SD = 4.75) than approach individuals (M = 13.64; SD = 6.57) but this difference was not significant, $t(52) = 1.54$, $p = .12$, $\eta^2 = .04$. It is unclear whether the failed replication was because the ambient testing environment had influenced the motivational orientation manipulation.

In Replication B (N = 48), we returned to our standard lab. The procedure was otherwise identical to Replication A. There were no differences between groups, $t(46) = .29$, $\eta^2 = .002$. However, our means were bimodally distributed, with entirely no measurements falling 20 decibels in between the modal peaks. We suspected that the bimodal distribution was caused by malfunctioning headsets because bimodal distributions are extremely rare in psychology, and the huge gap of 20 decibels is extremely abnormal and absent in other experiments reported here. The cause is probably an equipment failure. We subsequently used our own headsets for latter experiments.

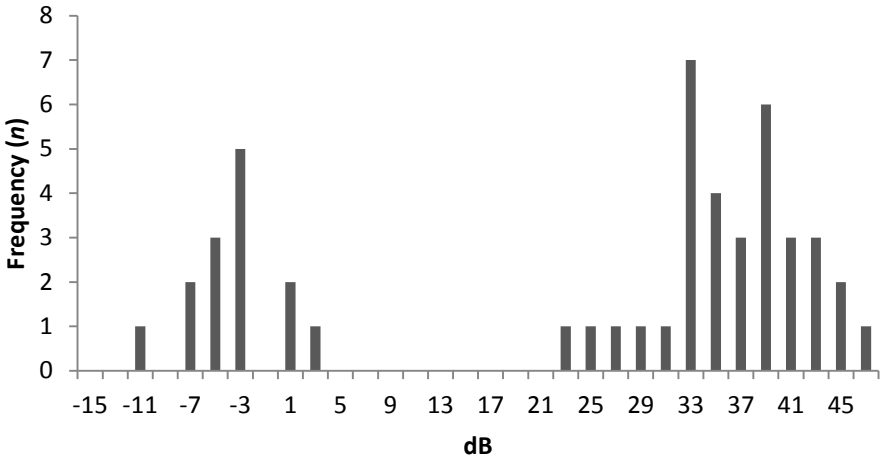

Figure A. Frequency distribution of decibels in Replication B.

Online Supplementary Material

Distance advantage

A difference in sound power also has a distance advantage. At sound level *L* and distance *r*, the formula relating sound power to distance is:

$$L_2 = L_1 - |\, 20 \cdot log \frac{r_2}{r_1} |$$

Every doubling of distance results in a 6 dB difference. At threshold level, avoidance individuals' detection advantage in distance is 0.22. In other words, avoidance individuals would be able to detect the sound made by one hissing snake at threshold level 1 m away, whereas approach individuals would detect the snake only when it is as near as 0.78 m.

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ENGLISH SUMMARY

Most people have no problems seeing the letters on this page. Indeed human sensory systems are well-adapted to detect things within specific environments. In some situations, however, one's visual perceptual system may be stretched to its limits. For example, when the print is fading away, the letters becomes increasingly difficult to read, to the extent that it eventually becomes "invisible". Without altering physical properties of the environment such as lighting conditions, will there be psychological states where extremely faint stimuli may become more detectable? In this dissertation, I argue that one's motivational orientation is one such psychological state that can alter perceptual limits.

Psychophysicists have mainly been concerned with understanding how the structural characteristics of a stimulus influence the perceptual detection. For decades, detection thresholds were thought to be independent from one's motivational or emotional states. Indeed any research that tried to prove otherwise was accused of being "psychoanalytic". Recently, this view has slowly shifted. Researchers have consistently found that fear, an avoidant emotion, improves contrast sensitivity, spatial resolution, and temporal resolution. However, these studies focused only on vision. In this dissertation, I extended this line of research to olfaction and audition.

In Chapter 1, I present a framework on the influence of avoidant emotions on *perceptual limits*, boundaries placed on perception abilities. Perceptual threshold—the main focus of my research—is one of these limits. The main thrust of my argument is that avoidant emotions such

as fear and disgust are important for survival. One of the functions they serve is that they aid detection of things in our environment by shifting perceptual thresholds, allowing organisms to detect things they would otherwise have not been able to detect. However, I also cautioned against an overly simplistic generalization that avoidant emotions would influence *all* possible perceptual limits, based purely on evolutionary arguments. Any such proposition needs to consider what not only evolutionary functions of emotions, but also consider what functions perceptual systems serve, and the plausibility of the underlying neurobiological and neural mechanisms.

In Chapter 2, I present empirical studies testing the influence of the avoidant emotions, fear and disgust, on olfactory detection thresholds. I presented stimuli that induced disgust (e.g., rotten food) or fear (e.g., weapon), while intermittently assessing their olfactory threshold. The key findings were that disgust and fear both lower sensory thresholds, especially for those who are highly prone to experience disgust in daily life (high disgust sensitivity).

One limitation from the experiments reported in Chapter 2 is that I had used only *n*-butanol to assess olfactory thresholds. *N*-butanol incidentally has an unpleasant smell. Hence it is unclear whether disgust lowers olfactory thresholds because disgust influences general olfactory sensitivity, or because of the fit between the negative valence of the scent and disgust. The objective of Chapter 3 was to tease apart these two explanations. In Chapter 3, instead of using *n*-butanol, I also used a pleasant scent, phenylethanol (rose scent). The key result was that disgust lowered olfactory thresholds for both of these scents. Hence it appears that disgust influences general olfactory sensitivity.

In Chapter 4, I investigated whether inducing a general avoidant motivational orientation would influence perceptual limits, but this time in a different modality – audition. I found that when participants adopted an arm posture known to trigger an avoidant motivational orientation, their auditory thresholds were lowered compared to control participants who adopted an arm posture known to trigger an approach motivational orientation. This effect was only restricted to high frequency sound stimuli. Subsequent experiments showed that this was because high frequency sound stimuli had negative valence.

In conclusion, the theoretical review outlined in Chapter 1 brings new insights on how avoidant emotions enhances perceptual limits and charts new directions on how to conceptualize the functional role of avoidant emotions vis-à-vis the functional role of sensory systems. Chapters 2 – 4 extended previous research from vision to olfaction and audition which previous research has not examined. Together, this dissertation has advanced our understanding on what it means to say that avoidant emotions enhance perception.

NEDERLANDSE SAMENVATTING

De meeste mensen ervaren geen moeite met het lezen van de letters op deze pagina. Onze sensorische systemen zijn dan ook goed aangepast om dingen te detecteren in specifieke omgevingen. Echter, in sommige situaties komt het voor dat ons visuele perceptuele systeem tot aan zijn grenzen wordt getest. Bijvoorbeeld wanneer de inkt steeds dunner wordt, waardoor de letters steeds moeilijker leesbaar worden, tot aan het moment dat de letters uiteindelijk 'onzichtbaar' worden. Als de fysieke eigenschappen van de omgeving (zoals lichtomstandigheden) gelijk blijven, zijn er dan psychologische staten waarin extreem zwakke stimuli beter detecteerbaar zijn? In dit proefschrift beargumenteer ik dat differentiële motivationele oriëntaties dergelijke psychologische staten zijn die perceptuele grenzen kunnen beïnvloeden.

Psychofysici hebben zich vooral bezig gehouden met het begrijpen van hoe de structurele kenmerken van een stimulus perceptie beïnvloeden. Gedurende decennia werd gedacht dat detectiedrempels onafhankelijk waren van motivationele of emotionele staten. Onderzoek dat probeerde deze link aan te tonen werd afgedaan als zijnde 'psychoanalytisch'. Sinds kort is deze gedachte langzaam aan het veranderen. Onderzoekers hebben vastgesteld dat angst, een 'vermijdende' emotie, de contrastgevoeligheid en de resolutie van ruimte en tijd verbetert. Deze set van studies richtte zich echter uitsluitend op visuele perceptie. In dit proefschrift heb ik deze lijn van onderzoek uitgebreid naar reuk- en hoorvermogen.

In Hoofdstuk 1 heb ik een kader geschetst over de invloed van vermijdende emoties op perceptuele grenzen. De perceptuele

drempel—de belangrijkste focus van mijn onderzoek—is een van die grenzen. Het belangrijkste onderdeel van mijn argumentatie is dat vermijdende emoties zoals angst of afkeer belangrijk zijn om te overleven. Een van de belangrijkste functies van vermijdende emoties is het in staat stellen perceptuele drempels te veranderen, waardoor organismen dingen kunnen waarnemen die zij anders niet zouden kunnen waarnemen. Ik was mij er wel van bewust dat ik niet een te simplistische generalisatie zou maken; dat vermijdende emoties alle mogelijke perceptuele grenzen zouden beïnvloeden, uitsluitend gebaseerd op evolutionaire argumentatie. Elk dergelijk voorstel moet overwegen waartoe niet alleen evolutionaire functies van emoties dienen, maar ook waartoe functies van perceptuele systemen dienen, evenals de plausibiliteit van de onderliggende neurobiologische en neurale mechanismen.

In Hoofdstuk 2 heb ik een aantal empirische studies beschreven die de invloed van vermijdende emoties, angst en afkeer, testen op drempels van reukvermogen. Ik stelde proefpersonen bloot aan afbeeldingen die afkeer (bijvoorbeeld rottend voedsel) of angst (bijvoorbeeld een wapen) veroorzaakten terwijl ik de drempels van hun reukvermogen testte. De belangrijkste bevindingen waren dat zowel angst als afkeer resulteerden in lagere sensorische drempelwaarden, vooral voor diegenen die zeer gevoelig zijn voor het ervaren van afkeer in het dagelijkse leven (mensen met een hoge 'afkeer-sensitiviteit').

Een beperking van de in Hoofdstuk 2 gerapporteerde studies is dat *n*-butanol werd gebruikt om drempels van reukvermogen te beoordelen. *N*-butanol heeft namelijk een enigszins onaangename geur. Vandaar dat het onduidelijk was of afkeer de drempels van reukvermogen verlaagt óf omdat afkeer de gevoeligheid van het

reukvermogen beïnvloedt, óf door de match tussen de negatieve valentie van de geur en de emotionele staat van afkeer. Het doel van Hoofdstuk 3 was om deze twee verklaringen te onderscheiden. In Hoofdstuk 3 heb ik in plaats van *n*-butanol ook een aangename geur (fenylethanol, ofwel rozengeur) gebruikt. Het belangrijkste resultaat was dat afkeer de drempels van reukvermogen voor beide geuren verlaagde. Dit duidt aan dat afkeer de algemene gevoeligheid van ons reukvermogen beïnvloedt.

In Hoofdstuk 4 onderzocht ik of het induceren van een motivationele vermijdingsoriëntatie perceptuele grenzen zou beïnvloeden; dit keer in een andere modaliteit, namelijk hoorvermogen. Ik ontdekte dat bij deelnemers die een armhouding aannamen die bekend staat om het veroorzaken van een motivationele vermijdingsoriëntatie, auditieve drempels lager waren. Dit, in vergelijking met deelnemers die een armhouding aannamen die bekend staan om het veroorzaken van een motivationele toenaderingsoriëntatie. Dit effect beperkte zich tot geluidsstimuli met een hoge frequentie. Vervolgonderzoek toonde aan dat dit was omdat de geluidsstimuli met een hoge frequentie een negatieve valentie hadden.

Concluderend, het theoretisch kader dat ik in Hoofdstuk 1 heb geschetst brengt nieuw inzicht in hoe vermijdende emotionele staten de perceptuele grenzen verbeteren. Daarnaast beschrijft het nieuwe richtlijnen over hoe de functionele rol van vermijdende emoties kan worden geconceptualiseerd in relatie tot de functionele rol van sensorische systemen. De hoofdstukken 2 tot en met 4 verbreden de scope van eerder onderzoek van het visuele domein naar reuk- en hoorvermogen, twee domeinen die nog niet eerder op een dergelijke

manier zijn onderzocht. Kortom, dit proefschrift verbreedt onze kennis over wat het betekent dat vermijdende emotionele staten de perceptie verbeteren.

Translated by Dr. Maikel Hengstler

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BIOGRAPHY

Kai Qin Chan obtained his Bachelor and Master of Social Sciences (Psychology) from the National University of Singapore in 2009 and 2011 respectively. In 2011, he began his doctoral candidature at Radboud University, under the supervision of Prof dr. Rob Holland and Prof dr. Ad van Knippenberg. He is currently Assistant Professor of Psychology, as well as Psychology Program Coordinator, at Ashoka University, India. Besides the research mentioned in this dissertation, he has also published "Differential impact of affective and cognitive attributes under deliberation and distraction" (2015: *Frontiers in Psychology*), "Sweet love: The effects of sweet taste experience on initial romantic perceptions" (2015: *Journal of Social and Personal Relationships*), "Taking a leap of faith: Reminders of God lead to greater risk taking" (2014: *Social Psychology & Personality Science*), "What do love and jealousy taste like?" (2014: *Emotion*), "Nudging you behind your back: The influence of friendship mental representations on risk taking propensity" (2012: *Journal of Social and Personal Relationships*). However, his proudest "publication" is an interview he gave for the Association of Psychological Science's *Observer*, titled "Ashoka Builds Science-Centric Psychology Program". He has also served as an ad-hoc reviewer for the *Journal of Experimental Social Psychology*, *Journal of Environmental Psychology, Social Psychology & Personality Science*, and *International Journal of Psychology*. For more information regarding his research and teaching interests, visit chankaiqin.weebly.com and teachingpsychology.weebly.com.

He loves the precision of the Dutch language, and his favorite Dutch word is *lekker*.

He is blissfully married to Gayl Teo and they are eagerly awaiting keys to their new apartment, which will be ready in 2020.